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Montefiore - Levy

ESSAY

ON

THE USE OF VARIOUS ALLOYS,

ESPECIALLY OF

PHOSPHOROUS BRONZE,

FOR

THE FOUNDING OF CANNON.

BY

C. MONTEFIORE-LEVY AND C. KUNKEL,
CIVIL ENGINEER. DOCTOR OF SCIENCES.

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TRANSLATED FROM THE FRENCH BY JOHN D. BRANDT, CHIEF CLERK
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INTRODUCTION.

During many years we had undertaken experiments for the improvement of alloys used in the fabrication of ordnance, especially by the addition of nickel; and about 1860, at our request, a series of trials were made, in the royal cannon foundery at Liége, upon the effect of the addition of nickel to the melting. The results of these trials demonstrated that whilst it produces an increase of resistance, this increase is not proportional to the expense caused by the addition of a given quantity of nickel.

In 1867-'68 M. A. Lavroff, colonel of artillery, Russian Guards, was ordered by his government to make, with us, a series of trials of the modifications produced in the resistance of bronze for cannon by different compositions and various modes of fabrication, and especially by the addition of nickel. The result of that great work being the property of the Russian government, we cannot speak of it in detail.

Among the experiments mentioned further on, those relating to ordinary bronze are, for the most part, a repetition of the most remarkable trials made in the first work.

It is very difficult, if not impossible, to procure exact or even comparative data on the resistance of metals designed especially for ordnance, (*au tir*;) for although work of this kind has been undertaken several times, and in different countries, no sufficient account has been taken of the influence, albeit very considerable, of the temperature of the casting, the method of cooling, and the physical constituents and form of the proof-bars. The disagreement in figures given by various authors for the resistance of an alloy of the same composition proves how great these influences are.

Therefore, before entering into a detail of our experiments, we propose to describe the course we have followed, and the processes which we have employed.

THE HISTORY OF

THE UNITED STATES OF AMERICA

The history of the United States of America is a story of a young nation that grew from a small colony of English settlers to a powerful republic. The story begins in 1492 when Christopher Columbus discovered the New World. The first English settlers arrived in 1607 at Jamestown, Virginia. Over the years, more settlers came, and the colonies grew. In 1776, the colonies declared their independence from Great Britain. The American Revolution followed, and the United States was born. The new nation faced many challenges, including the Civil War, but it emerged as a stronger and more unified country. Today, the United States is a leading power in the world, known for its freedom, innovation, and diversity.

METALS EMPLOYED.

COPPER.

For all our trials we have used either the best-selected copper from the manufactory of Messrs. Pascoe-Grenfell & Son, Swansea, or the buttons made in punching sheets of copper for the hearths of locomotives.

We wished to use the Pachkoff copper, and received samples of it from several metal-dealers; but these were proved by analysis to be of such impurity that we were obliged to reject them. We found the English copper very superior.

Having addressed M. Pachkoff directly on the subject, he informed us that for many years he had not made a single delivery of copper outside of Russia, and consequently he could not admit that these samples might be of his production.

TIN.

A part of our trials, and especially those with alloys of tin, copper and manganese, were made with Banca tin; all the rest with a tin almost chemically pure, produced by the wet process in our works at Val-Benoît.

NICKEL.

The nickel used was that prepared for us at Val-Benoît, by the wet process, completely freed from arsenic, and containing as impurities only traces of sulphur, and about three-tenths per cent. of iron.

MANGANESE.

All the alloys containing manganese were prepared with manganese-ciferous copper produced by the reduction in a cupola of a mixture of oxide of copper and oxide of manganese, both precipitated by the wet process.

PHOSPHORUS.

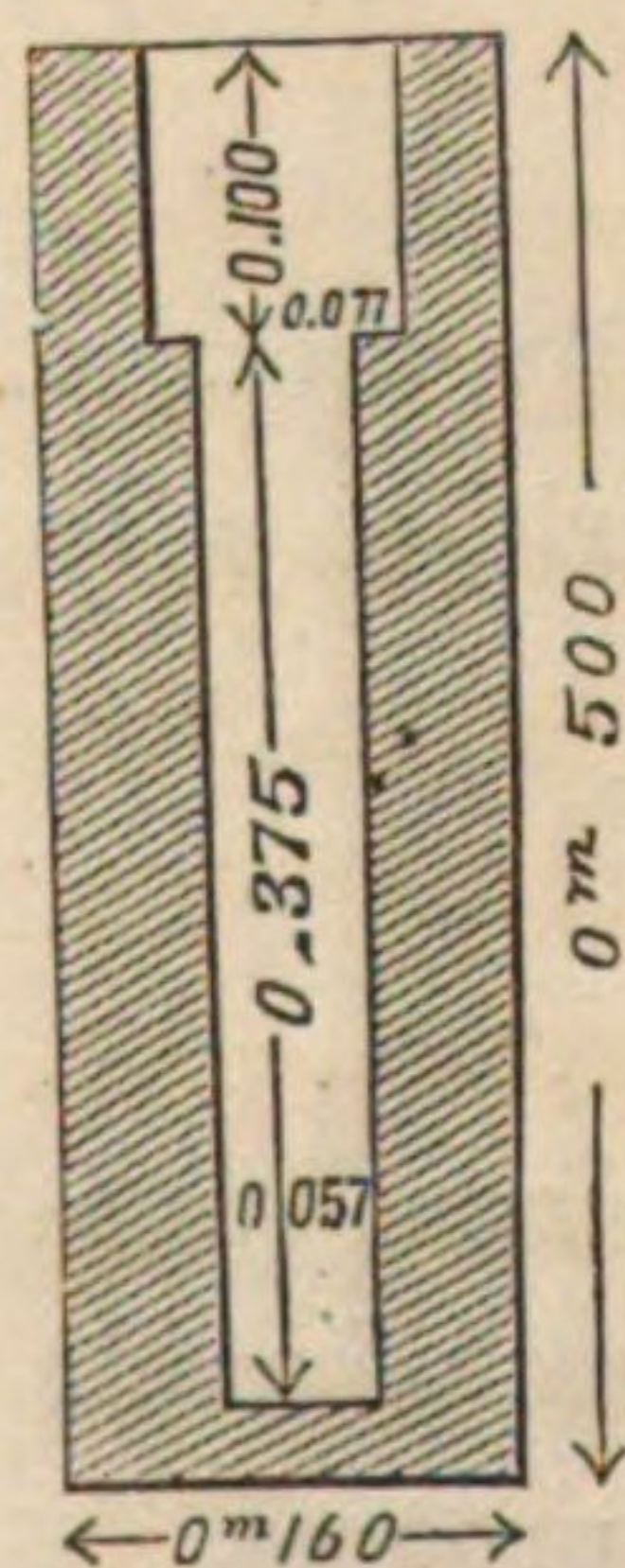
Phosphorus was introduced in the alloys, sometimes under the form of phosphuret of copper, sometimes under that of the phosphuret of tin. In treating, further on, of the phosphorous alloys, we will revert to the preparation of these combinations.

FUSION OF THE ALLOYS.

The fusion of the alloys was made in graphite crucibles, under a layer of charcoal. For all the trials of resistance the metal was recast at least twice, and very often three and four times, if the first bars were not satisfactory. This condition increased, without doubt, the practical value of the results obtained, in that it comes near the ordinary conditions of fabrication in recasting old cannon.

We believe it our duty to call attention to the extreme difficulty which one meets in producing, by successive operations, a given number of proof-bars cast at temperatures which have been decided upon, and of a fixed composition. Thus, in our investigations in ordinary bronze, we had to produce eighteen bars with 10 per cent. of tin in them, and cast at three different temperatures, the error in the composition not to exceed one-tenth per cent., and in the temperature 100 degrees. Under these conditions we had to cast not less than ninety bars in order to reach the desired result.

CASTING THE PROOF-BARS.



The casting of the proof-bars was made in an ingot-mold, of the form and dimensions shown in the opposite sketch. This mold, made in two similar halves, weighed 80 kilogrammes, (176.38 pounds,) and the proof-bar, with its false lug, weighed 12 to 13 kilogrammes.

Before casting the proof-bar the interior of the molds was coated with a mixture of turpentine and lamp-black, and, accordingly as a quick or slow cooling was desired, the casting was made in the mold, left cold, or previously brought to a red heat.

DETERMINATION OF THE TEMPERATURES OF THE CASTINGS.

The temperature of the casting was determined by throwing a portion of metal into a given quantity of water contained in a wooden pail, the temperature of the water being taken before and after the injection; also, the weight of the metal thrown in. The temperature was then computed by the following formula:

$$x = \frac{P'(t' - t)}{Pc} + t'$$

P' = weight of water.

P = weight of cast metal.

t = temperature of water before metal is thrown in.

t' = temperature of water after metal is thrown in.

c = specific heat of the alloy, assuming for these specific heats the figures of Regnault—

Copper	=	0.09515	Tin	=	0.05623
Nickel	=	0.10863	Manganese	=	0.14411
Phosphorus	=	0.18870	Zinc	=	0.09555

The figures which we give as the result of these computations will not be exact, since sufficient data are wanting of the specific heat of metals at different temperatures; but they serve for comparison; and to enable them to be rectified, if more exact data of specific heats are obtained, we give for each determination all the elements of our calculation.

SPECIFIC GRAVITY.

We desired, in each experiment, to determine not only the specific gravity of the alloy, but also the proportion of cavities existing in the bar.

The specific gravity of the complete bar, turned for the proof of resistance, was determined by means of a balance sensitive to a demi-gramme with a weight of 10 kilogrammes. From the bottom and top of the bar there were then sawed two specimens, weighing each 5 to 10 grammes, the

specific gravity of which, after boiling and cooling in a large quantity of distilled water, was determined very exactly by means of a balance sensitive to the tenth of a milligramme with a weight of 100 grammes. By a comparison of the results thus found, the interior defects of the bar could be noted; and we have in general rejected all those of which the specific gravity showed a difference of more than 3 per cent. with the highest specific gravity of two detached specimens. It became necessary, in that case, to change the conditions of casting or of cooling.

Meanwhile we made a certain number of trials with bars showing a difference of more than 3 per cent.; and the result of the sum of these trials is that the proofs of resistance for an alloy of the same composition are in very exact relation with the constitution of the alloy, such as results from a comparison of specific gravities.

ANALYSIS.

Specimens taken from the top or bottom of the bars, or from the place of rupture after the trials for resistance, served for the purpose of analysis.

The determination of the different substances was made in the following manner:

TIN.

The bronzes and alloys of tin containing no phosphorus were oxidized with nitric acid, and the solution, evaporated to dryness, was taken up again by nitric acid and supersaturated by ammonia, with the addition of a little chloride of ammonium. The hydrate of stannic acid was washed with water containing a little chloride of ammonium, and weighed, after calcination, in the state of anhydrous stannic acid. If the alloy contained a little iron, this was removed by dilute sulphuric acid; the weight of the oxide was then determined, and deducted from that found for the stannic acid.

The phosphorous bronzes were dissolved in aqua regia, and the precipitated metals, (copper and tin,) in the state of sulphurets, were made to run through the solution diluted by a current of sulphurous acid. These sulphurets, being separated by filtration with phosphoric acid, were peroxidized by aqua regia, and the remainder of the operation followed the process indicated above.

COPPER.

The copper was precipitated from its acid solution by sulphurous acid, the sulphuret dried upon the filter, calcined, with the addition of sulphur, in a current of hydrogen, and the copper weighed in the state of hemi-sulphuret.

NICKEL.

The same course would be followed for nickel as for copper, were it not that the precipitation by sulphurous acid is made without the solution slightly saturated with ammonia.

Being convinced, in the mean time, that the hemi-sulphuret of nickel has not a constant composition, we redissolved the solution, after weighing, by means of barytes, in order to ascertain the quantity of sulphur contained. This quantity of sulphur deducted from the hemi-sulphuret gives the exact weight in nickel.

MANGANESE.

The manganese, precipitated by the carbonate of soda, was weighed, after calcination, in the state of intermediary oxide of manganese, ($\text{Mn}^3 \text{O}^4$.)

PHOSPHORUS.

The phosphorus separated, as we have said before, from the metals by a current of sulphurous acid, was precipitated in the state of ammoniacomagnesian phosphate; and this precipitate having been washed with water of ammonia, and calcined, was weighed in the state of phosphate of magnesia.

LIQUATION.

Each alloy was subjected to a trial of liquation, to ascertain if, by slow cooling, it separated into one or more alloys of different compositions.

For this purpose 5 to 10 kilogrammes of alloy were melted in a crucible, which was not removed from the furnace until after the fusion was complete. This crucible was then placed on cold sand, and left there until a solid crust formed on the surface. It was then tapped with an iron rod, and all the liquid metal run off. Afterward the crucible was replaced on a hearth-plate, and, very often during the final cooling, a new portion of the alloy was run off, having a different composition from that first cast. The different products obtained in this manner were analyzed separately.

FORM AND PREPARATION OF THE PROOF-BARS.

The form of the proof-bars has evidently the greatest influence upon the results obtained in the trials of resistance, and these results cannot be compared without knowing the form of the bars which have been used elsewhere.

Thus, in the trials which were made in America, the results of which are recorded in the "Reports of experiments on the strength and other properties of metal for cannon, Philadelphia, 1856," proof-bars were used of the form used at figure No. 1, on the opposite page.

A form analogous to this, No. 2, is in use at the Woolwich arsenal, and was employed by Colonel Wilmot in the trials of Bessemer steel, and in those made by Mr. Barlow, in 1861, on different qualities of steel. Now it is evident that this form not only gives a single minimum section, but also reinforces that section; since, if we take a cylindrical form, we have an infinity of equal sections in normal conditions.

The result of the trial is, therefore, in this latter case, much nearer the truth.

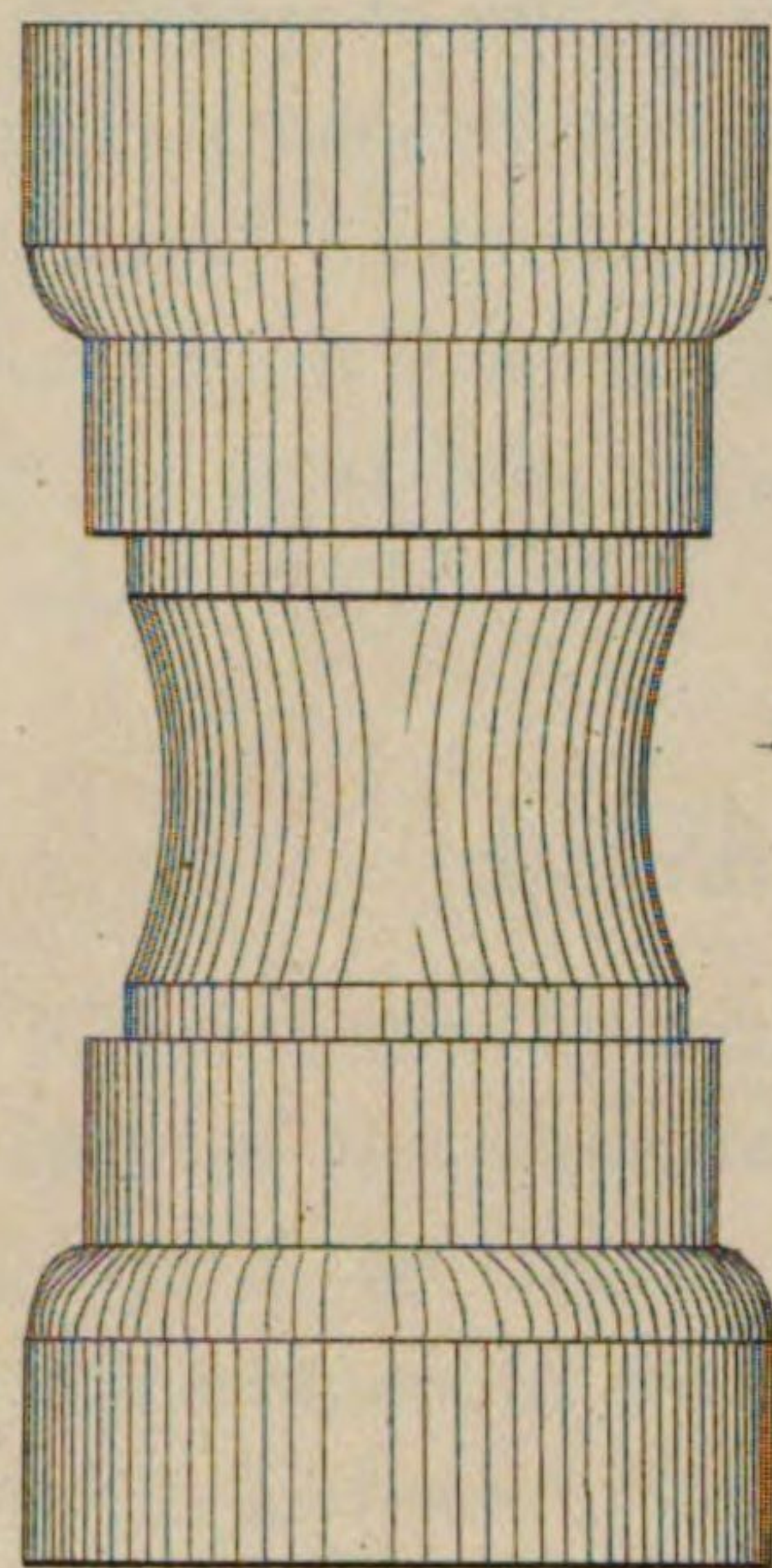
Finally, here is a conclusive example on this subject. Colonel Wilmot, using proof-bars of the form mentioned above, found, as the result of eight trials for absolute resistance in Bessemer steel, the following figures:

Mean = 153,677 English pounds per square inch.
 Highest figure = 162,974 English pounds per square inch.
 Lowest figure = 136,490 English pounds per square inch.

The same steel tried with proof-bars turned cylindrically to a section of one square inch on a length of three inches, as in the trials of Mr. Kirkaldy, gave the following result:

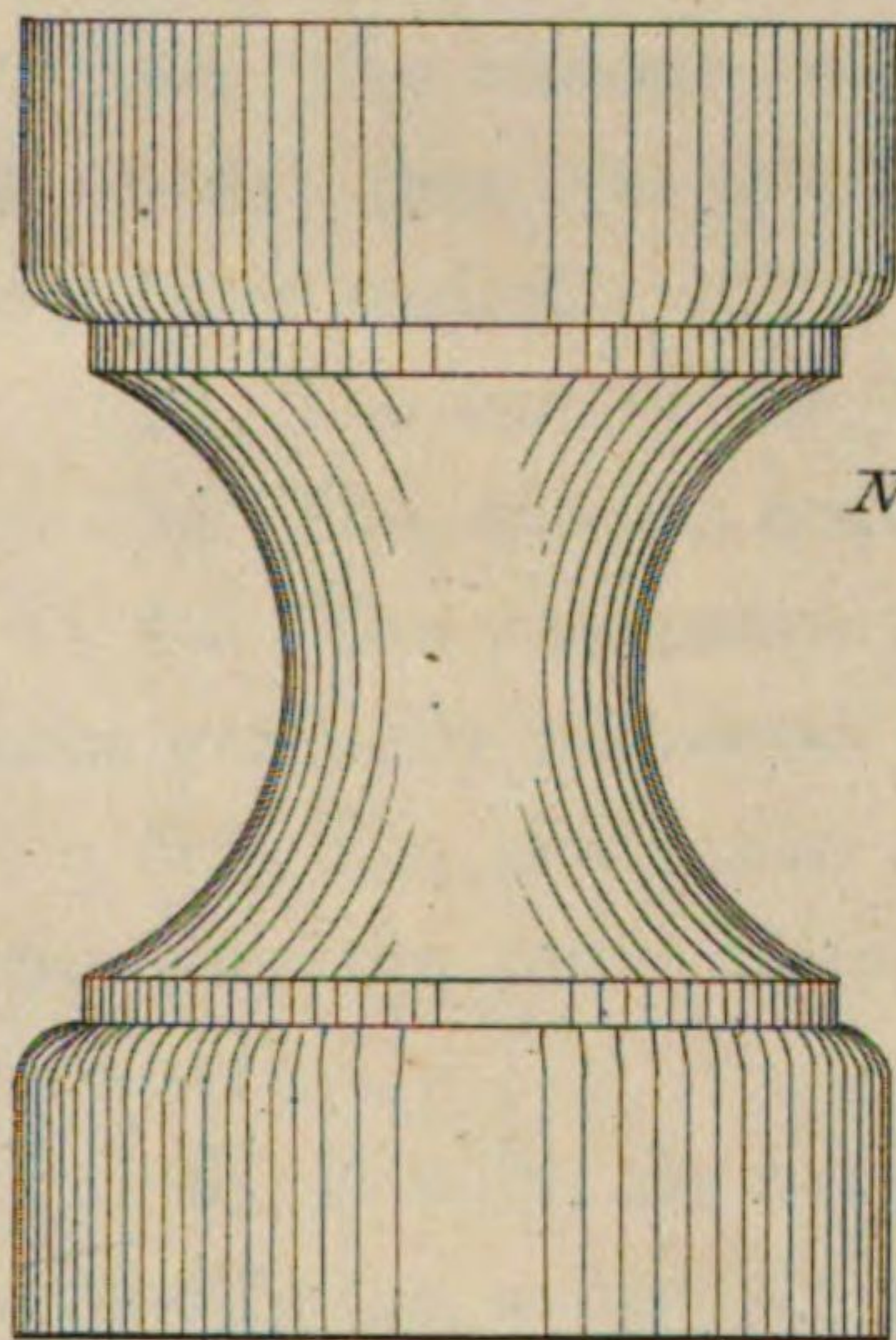
Mean = 114,460 English pounds per square inch.
 Highest figure = 123,165 English pounds per square inch.
 Lowest figure = 103,255 English pounds per square inch.

It is seen, therefore, that the form of the bar had the effect of giving, with the same identical metals, results differing in the proportion of 100 to 138.



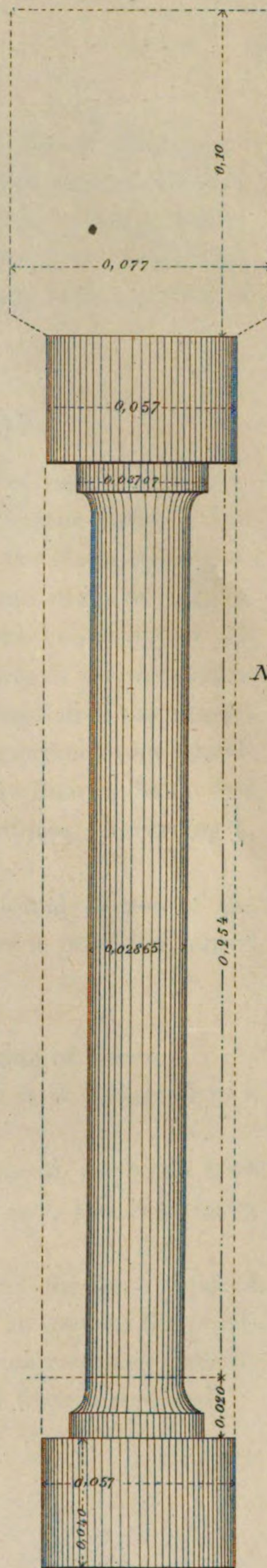
N° 1.

grandeur d'exécution



N° 2.

grandeur d'exécution.



N° 3.

demi grandeur d'exécution.

Wishing to obtain exact data concerning the elasticity of alloys, their elongation under a strain gradually increased, the contraction of areas at the point of fracture and their minimum resistance, which, by consequence, is that upon which absolute reliance could be placed, we selected form No. 3 for the proof-bars, turned cylindrically ten inches long with a section of one square inch.

DETERMINATION OF RESISTANCE.

To ascertain, by trials of resistance, the true value of metals, the determination of the absolute resistance alone will by no means suffice. Not only is it of the highest interest to know the value of the *elastic* resistance, and the manner in which the metal behaves under the strain of weights gradually increased, but also, (since it is evident that the knowledge of the absolute resistance is of ordinary interest,) if the *elasticity* of the metal submitted to proof is not noted, it is certain that the consideration of the relation of the original section furnishes data of the highest importance to a knowledge of the hardness of the metal. It seems to us more than probable that this relation gives an exact indication of the relative hardness. Accordingly, the object of our trials was to determine—

1st. The *absolute resistance* calculated on the original section of the proof-bar; that is to say, the force required to fracture a proof-bar turned to a given section.

2d. The area of the *fractured* section of the bar.

3d. The *absolute* resistance calculated on this section of fracture.

4th. The successive elongations of the bar while it is subjected to a force gradually increased.

5th. The elongation of the bar at various periods of the trials after removing the force which acted upon it; that is to say, the PERMANENT ELONGATION.

6th. Finally, the ELASTIC RESISTANCE; that is to say, the force required to modify the molecular constitution of the alloy, and to prevent the proof-bar, which is stretched under the action of this force, from resuming exactly, or even to a small degree, its primitive length after the force is removed.

APPARATUS EMPLOYED IN THE TRIALS OF RESISTANCE.

The trials of resistance, as well as the exact turning of the proof-bars, were made at the proof establishment of Mr. David Kirkaldy, Southwark street, London, an establishment unique of its kind in all that relates to precision of details and the multiplicity of its appliances.

It has lathes in which a cylindrical bar may be turned with exactness to one-hundredth of a line nearly, and a hydraulic press admirably arranged for trials of every kind, and capable of exerting a pressure of one million of pounds, English, by a system of counterpoised levers, whilst the pressure is indicated even to the tenth of a pound nearly. A detailed description of this machine will be found in the London Mechanics' Magazine of the 9th March, 1866.

ORDINARY BRONZE.

As a base for all the trials of ordinary bronze we have adopted the proportion of 10 per cent. of tin and 90 per cent. of copper.

Wishing to assure ourselves of the effect of oxidation on the composition of bronze subjected to successive remeltings, we remelted an ordinary bronze many times in an open crucible, obtaining therefrom the following results:

	Tin.	Copper.
The bronze employed contained.....	10.1	89.9
After the first recast it contained.....	9.82	90.18
After the second recast it contained.....	9.40	90.60
After the third recast it contained.....	9.16	90.84
After the fourth recast it contained.....	8.52	91.48

LIQUATION.

First trial.—In fusing and cooling 10 kilogrammes of ordinary bronze, containing 10.1 per cent. of tin, in the manner described above, we have obtained the following results:

	Tin.	Copper.
Composition of the bronze.....	10.1	89.9
Metal solidified in crucible.....	8.96	91.04
Metal cast after piercing the solidified crust.....	11.22	88.78
Metal run off from the solidified part during the cooling..	17.62	82.38

Second trial.—In operating in the same manner upon 8 kilogrammes of bronze, containing 9.62 per cent. of tin, we obtained the following results:

	Tin.	Copper.
Composition of the bronze.....	9.62	90.38
Metal solidified in crucible.....	8.92	91.08
Metal cast after piercing the solidified crust.....	10.74	89.26
Metal run off from the solidified part during the cooling..	18.10	81.90

Third trial.—Operating in the same way upon 12 kilogrammes of bronze, containing 8.9 per cent. of tin, the following results were obtained:

	Tin.	Copper.
Composition of the bronze.....	8.90	91.10
Metal solidified in the crucible.....	7.24	92.76
Metal cast after piercing the solidified crust.....	9.30	90.70
Metal run off from the solidified part during the cooling..	17.51	82.49

The result of these trials shows that the ordinary cannon-bronze, while cooling slowly in the molds, is subdivided into many alloys of different compositions. The alloy containing the most copper is first solidified, and those obtained by subsequent partial coolings are not of a uniform composition.

These trials seem, however, to prove that finally a fixed alloy, having a constant composition of $17\frac{1}{2}$ to 18 per cent. of tin and $82\frac{1}{2}$ to 82 per cent. of copper, is separated from these bronzes of different compositions.

TEMPERATURE OF FUSION OF CANNON-BRONZE.

We have endeavored to ascertain the temperature of fusion of bronze in determining that of the point of solidification, which ought not to be sensibly different.

Ten kilogrammes of bronze, containing 10 per cent. of tin, having been melted, the metal was allowed to cool in the crucible until a solid crust was formed. This crust having been pierced, a portion of the metal was poured into a given weight of water, the temperature of which had been noted; the temperature of the water, after the introduction of the metal, as well as its weight, was taken, and the following data were obtained:

Original temperature of water	= 24°50 C.
Weight of water	= 5 kilos.
Temperature of water after introduction of the metal	= 55°75 C.
Weight of metal	= 1.485 kilos.
Specific heat assumed	= 0.09126.

From which we obtain, by the formula given above, 1239° C. as the temperature of solidification or of fusion.

As we have said, we regard this determination as comparative, and not as the truth; and we believe that the real point of temperature is much lower.

According to Plattner, the fusing point of bronze, containing 10 per cent. of tin, is assumed as 1078° C.; but this determination is based upon the inadmissible opinion that the fusing point of an alloy would be proportional to the fusing point of the constituent metals.

In many books we find the figure 900° C. given as the fusing point of bronze; we are completely ignorant of the data upon which this figure is based.

Finally, in order to ascertain the influence upon the qualities of ordinary bronze of increasing the temperature of the melting more or less, and

of cooling the casting more or less rapidly, we made a series of trials, from which we extract the six following as examples :

We first cast in cold ingot-molds three bars, and then three other bars in molds heated red ; that is to say, between 700° and 800° C. In each series the first bar was cast at a high temperature, about 1800° to 2400° C. ; the second at a less temperature, about 1500° to 1700° C., and the third at a low temperature, about 1300° to 1400° C.

3 B

ORDINARY CANNON-BRONZE,

CAST AT A HIGH TEMPERATURE AND COOLED QUICKLY.

No. 1.

THE ANALYSIS OF THE BAR GAVE:

9.98 tin.
89.86 copper.

Total, **99.84**

Temperature of the water.....	21° C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	47° 50 C.
Weight of metal.....	0.630 kilo.
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF THE CASTING, **2309° C.**

The specific gravity of the turned bar was.....	8.623
The specific gravity of a specimen from top of bar.....	8.788
The specific gravity of a specimen from bottom of bar.....	8.836

The bar, therefore, contained—

2.41 PER CENT. OF CAVITIES AND **97.59** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.836**.

The trial under the hydraulic press gave the following:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.10 inches.
Section of bar at point of rupture.....	0.949 square inch.
Contraction of section.....	5.10 per cent.
Final permanent elongation.....	2.70 per cent.

We also obtained for an ordinary bronze, with 10 per cent. of tin and 90-per cent. of copper, cast at 2309° C., in a cold mold:

An *elastic* resistance of 15,300 pounds per square inch, or **1,075** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 25,160 pounds, or **1,769** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 26,512 pounds, or **1,863** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ORDINARY CANNON-BRONZE.

No. 1.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018	
10,500	0.019	
11,000	0.020	
11,500	0.022	
12,000	0.023	0.004
12,500	0.024	
13,000	0.025	
13,500	0.026	
14,000	0.028	0.006
14,500	0.030	
15,000	0.032	
15,500	0.035	
16,000	0.038	0.016
16,500	0.042	
17,000	0.046	
17,500	0.050	
18,000	0.058	0.024
18,500	0.068	
19,000	0.073	
19,500	0.080	
20,000	0.088	0.054
20,500	0.097	
21,000	0.106	
21,500	0.118	
22,000	0.130	0.116
22,500	0.142	
23,000	0.164	
23,500	0.188	
24,000	0.208	0.200
24,500	0.230	
25,000	0.280	
25,160	Rupture.	0.270

ORDINARY CANNON-BRONZE,

CAST AT A MEAN TEMPERATURE AND COOLED QUICKLY.

No. 2.

THE ANALYSIS OF THE BAR GAVE:

10.06 tin.**89.70** copper.Total, **99.76**

Temperature of the water.....	23° C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	46° 25 C.
Weight of metal.....	0.518 kilo
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF THE CASTING, **1602° C.**

The specific gravity of the turned bar was.....	8.746
The specific gravity of a specimen from top of bar.....	8.870
The specific gravity of a specimen from bottom of bar.....	8.863

The bar, therefore, contained—

1.41 PER CENT. OF CAVITIES AND **98.59** PER CENT. OF METAL OF A SPECIFIC GRAVITY OF **8.870**.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.08 inches.
Section of bar at point of rupture.....	0.916 square inch.
Contraction of the section.....	8.4 per cent.
Final permanent elongation.....	4.0 per cent.

We also obtained for an ordinary bronze, with 10 per cent. of tin and 90 per cent. of copper, cast at 1602° C., in a cold mold:

An *elastic* resistance of 19,700 pounds per square inch, or **1,385** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 29,534 pounds, or **2,076** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 32,242 pounds, or **2,266** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ORDINARY CANNON-BRONZE.

No. 2.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.027	
10,500	0.028	
11,000	0.029	
11,500	0.030	
12,000	0.031	
12,500	0.032	
13,000	0.033	
13,500	0.034	
14,000	0.035	0.000
14,500	0.036	
15,000	0.037	
15,500	0.038	
16,000	0.040	0.003
16,500	0.042	
17,000	0.044	
17,500	0.046	
18,000	0.048	0.008
18,500	0.050	
19,000	0.053	
19,500	0.056	
20,000	0.063	0.018
20,500	0.072	
21,000	0.081	
21,500	0.090	
22,000	0.098	0.048
22,500	0.110	
23,000	0.122	
23,500	0.134	
24,000	0.152	0.108
24,500	0.164	
25,000	0.180	
25,500	0.190	
26,000	0.218	0.168
26,500	0.238	
27,000	0.276	
27,500	0.300	
28,000	0.335	
28,500	0.368	
29,000	0.404	
29,500	0.438	
29,534	Rupture.	0.400

ORDINARY CANNON-BRONZE,
CAST AT A LOW TEMPERATURE AND COOLED QUICKLY.
 No. 3.

THE ANALYSIS GAVE:

10.34 tin.
89.14 copper.

Total, **99.48**

Temperature of the water.....	20° C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	43° 75 C.
Weight of metal.....	1.005 kilos.
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF THE CASTING, **1338° C.**

Specific gravity of the turned bar.....	8.664
Specific gravity of specimen from top of bar.....	8.981
Specific gravity of specimen from bottom of bar.....	8.899

The bar, therefore, contained—

3.33 PER CENT. OF CAVITIES AND **96.47** PER CENT. OF METAL WITH A
 SPECIFIC GRAVITY OF **8.981**.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at the point of rupture.....	1.100 inches.
Section of bar at the point of rupture.....	0.950 square inch.
Contraction of the section.....	5 per cent.
Final permanent elongation.....	2.4 per cent.

We obtained, also, with ordinary bronze of 10 per cent. of tin and 90 per cent. of copper, cast at 1338° C., in a cold mold:

An *elastic* resistance of 14,400 pounds per square inch, or **1,012** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 19,424 pounds, or **1,365** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 20,445 pounds, or **1,437** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ORDINARY CANNON-BRONZE.

No. 3.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.020	
10,500	0.022	
11,000	0.024	
11,500	0.025	
12,000	0.027	
12,500	0.028	
13,000	0.030	
13,500	0.031	
14,000	0.032	0.005
14,500	0.038	
15,000	0.041	
15,500	0.046	
16,000	0.051	0.014
16,500	0.055	
17,000	0.062	
17,500	0.069	
18,000	0.082	0.048
18,500	0.090	
19,000	0.100	
19,424	Rupture.	0.240

ORDINARY CANNON-BRONZE,

CAST AT A HIGH TEMPERATURE AND COOLED SLOWLY.

No. 4.

ANALYSIS OF THE BAR GAVE:

10.16 tin.

89.54 copper.

Total, 99.70

Temperature of the water.....	22°C.
Weight of water.....	5 kilos.
Temperature of water after the introduction of metal.....	48° 75 C.
Weight of metal.....	0.618 kilo.
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF CASTING, 2420° C.

The specific gravity of the turned bar.....	8.710
The specific gravity of sample from top of bar.....	8.681
The specific gravity of sample from bottom of bar.....	8.882

The bar, therefore, contained—

1.94 PER CENT. OF CAVITIES AND 98.06 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.882.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.11 inches.
Section of bar at point of rupture.....	0.964 square inch.
Contraction of section.....	3.60 per cent.
Final permanent elongation.....	1.00 per cent.

We obtained, also, for ordinary bronze, with 10 per cent. of tin and 90 per cent. of copper, cast at 2420° C., in a heated mold:

An *elastic* resistance of 12,800 pounds per square inch, or 900 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 16,650 pounds, or 1,170 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 17,272 pounds, or 1,214 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ORDINARY CANNON-BRONZE.

No. 4.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.026	
10,500	0.027	
11,000	0.031	
11,500	0.035	
12,000	0.040	0.008
12,500	0.042	
13,000	0.044	
13,500	0.047	
14,000	0.050	0.016
14,500	0.054	
15,000	0.057	
15,500	0.070	
16,000	0.082	0.045
16,500	0.102	
16,650	Rupture.	0.100

ORDINARY CANNON-BRONZE,

CAST AT A MEAN TEMPERATURE AND COOLED SLOWLY.

No. 5.

ANALYSIS OF THE BAR GAVE:

9.80 tin.

89.51 copper.

Total, **99.31**

Temperature of the water.....	23° C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	46° 33 C.
Weight of metal.....	0.825 kilo.
Assumed specific heat.....	0.09126

COMPUTED TEMPERATURE OF CASTING, **1595° C.**

Specific gravity of the turned bar.....	8.728
Specific gravity of sample from top of bar.....	8.760
Specific gravity of sample from bottom of bar.....	8.872

The bar, therefore, contained—

1.62 PER CENT. OF CAVITIES AND **98.38** PER CENT. OF METAL OF A SPECIFIC GRAVITY OF **8.872**.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.108 inches.
Section of bar at point of rupture.....	0.963 square inch.
Contraction of section.....	3.7 per cent.
Final permanent elongation.....	1.4 per cent.

We also obtained with ordinary bronze, containing 10 per cent. of tin and 90 per cent. of copper, cast at 1595° C., in a heated mold:

An *elastic* resistance of 13,300 pounds per square inch, or **935** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 16,540 pounds, or **1,163** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 17,071 pounds, or **1,200** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ORDINARY CANNON-BRONZE.

No. 5.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.027	
10,500	0.029	
11,000	0.031	
11,500	0.033	
12,000	0.035	0.005
12,500	0.036	
13,000	0.038	
13,500	0.040	
14,000	0.045	0.019
14,500	0.050	
15,000	0.068	
15,500	0.080	
16,000	0.098	0.060
16,500	0.140	
16,540	Rupture.	0.140

ORDINARY CANNON-BRONZE,

CAST AT A LOW TEMPERATURE AND COOLED SLOWLY.

No. 6.

ANALYSIS OF THE BAR GAVE :

10.15 tin.
89.26 copper.

Total, 99.41

Temperature of the water.....	23°50 C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	40°50 C.
Weight of metal.....	0.704 kilo.
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF CASTING, 1363° C.

Specific gravity of the turned bar.....	8.704
Specific gravity of sample from top of bar.....	8.826
Specific gravity of sample from bottom of bar.....	8.906

The bar, therefore, contained—

2.27 PER CENT. OF CAVITIES AND **97.73** PER CENT. OF METAL WITH A
SPECIFIC GRAVITY OF **8.906**.

The trial under the hydraulic press gave :

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.110 inches.
Section of bar at point of rupture.....	0.967 square inch.
Contraction of the section.....	3.3 per cent.
Final permanent elongation.....	2.0 per cent.

We obtained, also, with an ordinary bronze, having 10 per cent. of tin and 90 per cent. of copper, cast at 1363° C., in a heated mold :

An *elastic* resistance of 12,900 pounds per square inch, or **907** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 19,230 pounds, or **1,352** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 19,886 pounds, or **1,398** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ORDINARY CANNON-BRONZE.

No. 6.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.024	
10,500	0.026	
11,000	0.028	
11,500	0.031	
12,000	0.035	0.005
12,500	0.038	
13,000	0.039	
13,500	0.041	
14,000	0.044	0.014
14,500	0.046	
15,000	0.048	
15,500	0.050	
16,000	0.053	0.035
16,500	0.062	
17,000	0.074	
17,500	0.094	
18,000	0.122	0.110
18,500	0.160	
19,000	0.200	
19,230	Rupture.	0.200

It is shown by these trials that, for ordinary bronze, cooled either quickly or slowly, the most convenient temperature for the casting, and

which gives the greatest elasticity and resistance, is between 1500° and 1600° C.

Under these conditions the bronze which is quickly cooled presents an elastic resistance greater, in the proportion of 148 to 100, and an absolute resistance greater, in the proportion of 178 to 100, than those of the same metal cooled slowly.

THE USE OF OLD BRONZES.

The opinions of experts are exceedingly divided as to advantages resulting from the use of new metals, or of old bronzes, in the fabrication of cannon. Some are opposed to the use of old metals as producing less strength, on account of the dissolution of the metallic oxides; others, on the contrary, see in it an advantage on account of the greater homogeneity which results; but we do not believe that any theoretical trials specially designed to ascertain the truth concerning this delicate point have ever been made. In like manner, if the advocates of either of these metals made use of the puddling process, with green wood, to obtain a more perfect mixture, or to reduce a portion of the oxides which might be found in solution, we have not been able to find any of the results of the trials on the effect of this puddling.

It would be exceedingly difficult to determine, by analysis, the quantity of oxygen contained in a mixture of this kind; for the treatment of bronze in a current of hydrogen, in order to determine the quantity of water formed, requires, for the decomposition of the oxide of tin, a temperature much higher than that which can be used in analytical trials.

Meanwhile, we have been able to show, in an indirect way, that bronze dissolves the oxide.

By adding to old bronze, while in fusion, just before casting, a quantity of phosphorous bronze, in which the proportion of phosphorus is known, and having discovered by trial that phosphorus, in combination with a large proportion of copper and tin, is only slowly eliminated by the action of heat, we are certain that the whole decrease in the quantity added to old bronze corresponds nearly exactly to the oxygen contained in the bronze. Five trials, made under these conditions, have given us the following results:

PHOSPHORUS ADDED.	PHOSPHORUS FOUND IN THE BRONZE CASTING.	DIFFERENCE IN THE PROPORTION OF PHOSPHORUS.	OXYGEN CORRE- SPONDING TO THIS DIFFERENCE.
0.110	0.020	0.080	0.103
1.133	1.033	0.100	0.129
2.470	2.340	0.130	0.168
0.580	0.260	0.320	0.413
1.000	0.910	0.090	0.116

These trials demonstrate that bronze, when recast many times in contact with the air, absorbs oxygen. It is, moreover, evident that this oxygen is in the state of a dissolved oxide, probably the oxide of tin; for, if, instead of being in combination, this oxygen is found in a free state, it must have separated itself from the metal at the moment of cooling, as with copper, nickel, &c.; and there would be found, by the cavities also produced, a difference much superior to that which our trials have shown to exist between the specific gravity of whole bars and that of the detached specimens.

EFFECT OF PUDDLING.

In order to fix definitely the influence of a certain quantity of dissolved oxide, and the effect of stirring the metal, we have made the following trials: We kept in fusion, for a certain time, a sufficiently large quantity of old bronze, without a covering of charcoal, and from this alloy we cast a proof-bar. We then stirred the remaining metal briskly for a quarter of an hour with green wood, and cast a second proof-bar. Finally, we added to the last part a very small proportion of phosphorous bronze, and cast a third bar. The three bars were cast at a mean temperature, and in cold ingot-molds. The trials gave the following results:

CANNON-BRONZE,

CONTAINING MUCH OXIDE, CAST AT A MEAN TEMPERATURE AND
COOLED QUICKLY.

No. 7.

THE ANALYSIS OF THE BAR GAVE:

	9.96	tin.
	89.68	copper.
Total,	99.64	

Temperature of the water.....	23° C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	46°33 C.
Weight of metal.....	0.825 kilo.
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF THE CASTING, **1595° C.**

Specific gravity of the turned bar.....	8.741
Specific gravity of sample from top of bar.....	8.877
Specific gravity of sample from bottom of bar.....	8.840

The bar, therefore, contained—

1.53 PER CENT. OF CAVITIES AND **98.47** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.877**.

The trial under the hydraulic press gave:

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of bar at point of rupture.....	1.11 inches.
Section of bar at point of rupture.....	0.968 square inch.
Contraction of section.....	3.2 per cent.
Final permanent elongation.....	2.0 per cent.

We also obtained with an old bronze, rich in oxide, cast at 1595° C.,
in a cold ingot-mold:

An *elastic* resistance of 17,200 pounds per square inch, or **1,209** kilo-
grammes per square centimetre.

An *absolute* resistance of the original section of 22,982 pounds, or **1,616**
kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 23,760 pounds, or **1,670**
kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

CANNON-BRONZE, VERY OXIDIZED.

No. 7.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018	0.000
10,500	0.020	
11,000	0.021	
11,500	0.022	
12,000	0.023	0.002
12,500	0.024	
13,000	0.025	
13,500	0.025	
14,000	0.026	0.004
14,500	0.028	
15,000	0.030	
15,500	0.031	
16,000	0.033	0.007
16,500	0.035	
17,000	0.039	
17,500	0.043	
18,000	0.050	0.020
18,500	0.057	
19,000	0.064	
19,500	0.075	
20,000	0.087	0.070
20,500	0.101	
21,000	0.115	
21,500	0.130	
22,000	0.150	0.140
22,500	0.180	
22,982	Rupture.	0.200

OLD CANNON-BRONZE,

VERY OXIDIZED, STIRRED VIGOROUSLY, BEFORE CASTING, WITH
GREEN WOOD.

No. 8.

THE ANALYSIS OF THE BAR GAVE:

10.08 tin.

89.72 copper.

Total, **99.80**

Temperature of the water.....	22° 5 C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	50° 5 C.
Weight of metal.....	0.948 kilo.
Specific heat assumed.....	0.09126

COMPUTED TEMPERATURE OF THE CASTING, **1668° C.**

Specific gravity of the turned bar.....	8.517
Specific gravity of sample from top of bar.....	8.783
Specific gravity of sample from bottom of bar.....	8.839

The bar, therefore, contained—

3.63 PER CENT. OF CAVITIES AND **96.37** PER CENT. OF METAL WITH A
SPECIFIC GRAVITY OF **8.839**.

The trial under the hydraulic press gave:

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of the bar at point of rupture.....	1.11 inches.
Section of the bar at point of rupture.....	0.968 square inch.
Contraction of the section.....	3.2 per cent.
Final permanent elongation.....	2.8 per cent.

We obtained, also, with an old bronze, rich in oxide, stirred vigorously
with green wood, before casting:

An *elastic* resistance of 17,700 pounds per square inch, or **1,244** kilo-
grammes per square centimetre.

An *absolute* resistance of the original section of 24,972 pounds, or **1,755**
kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 25,798 pounds, or **1,813**
kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

OLD BRONZE, PUDDLED.

No. 8.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018	
10,500	0.019	
11,000	0.020	
11,500	0.021	
12,000	0.022	0.001
12,500	0.023	
13,000	0.025	
13,500	0.026	
14,000	0.028	0.003
14,500	0.030	
15,000	0.032	
15,500	0.034	
16,000	0.037	0.006
16,500	0.039	
17,000	0.041	
17,500	0.045	
18,000	0.050	0.013
18,500	0.055	
19,000	0.060	
19,500	0.066	
20,000	0.074	0.024
20,500	0.085	
21,000	0.098	
21,500	0.110	
22,000	0.123	0.080
22,500	0.135	
23,000	0.153	
23,500	0.177	
24,000	0.201	0.180
24,500	0.242	
24,972	Rupture.	0.280

CANNON-BRONZE,

VERY OXIDIZED, DEOXIDIZED BY THE ADDITION OF A SMALL QUANTITY OF PHOSPHORUS.

No. 9.

THE ANALYSIS OF THE BAR cast, after the addition of 10 per cent. of phosphorus, under the form of phosphorous bronze, to the metal remaining from the two preceding trials, gave :

9.94 tin.
0.02 phosphorus.
89.56 copper.

Total, **99.52**

Temperature of the water.....	23½° C.
Weight of water.....	5 kilos.
Temperature of water after introduction of metal.....	42½° C.
Weight of metal.....	0.714 kilo.

COMPUTED TEMPERATURE OF THE CASTING, **1514° C.**

Specific gravity of the turned bar.....	8.707
Specific gravity of sample from top of bar.....	8.816
Specific gravity of sample from bottom of bar.....	8.712

The bar, therefore, contained—

1.24 PER CENT. OF CAVITIES AND **98.76** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.816**.

The trial under the hydraulic press gave :

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.09 inches.
Section of bar at point of rupture.....	0.933 square inch.
Contraction of section.....	6.7 per cent.
Final permanent elongation.....	6.8 per cent.

We obtained, also, with an old bronze, very rich in oxide, deoxidized by some phosphorus, and cast in a cold ingot-mold at 1514° C. :

An *elastic* resistance of 19,300 pounds per square inch, or **1,356** kilogrammes per square centimetre.

An *absolute* resistance of the primitive section of 33,916 pounds, or **2,384** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 36,390 pounds, or **2,558** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

CANNON-BRONZE DEOXIDIZED WITH PHOSPHORUS.

No. 9.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.026	
10,500	0.027	
11,000	0.028	
11,500	0.029	
12,000	0.030	
12,500	0.031	
13,000	0.032	
13,500	0.033	
14,000	0.035	0.000
14,500	0.036	
15,000	0.037	
15,500	0.038	
16,000	0.040	0.003
16,500	0.042	
17,000	0.044	
17,500	0.048	
18,000	0.050	0.007
18,500	0.053	
19,000	0.056	
19,500	0.059	
20,000	0.063	0.015
20,500	0.067	
21,000	0.074	
21,500	0.078	
22,000	0.083	0.038
22,500	0.092	
23,000	0.098	
23,500	0.104	
24,000	0.115	0.074
24,500	0.132	
25,000	0.152	
25,500	0.171	
26,000	0.192	0.160
26,500	0.212	
27,000	0.236	
27,500	0.260	
28,000	0.285	0.262
28,500	0.310	
29,000	0.332	
29,500	0.360	
30,000	0.387	0.370
33.916	Rupture.	0.680

It results from these trials that whilst the old bronze gains by stirring, in *elastic* resistance and in absolute resistance, only 3 per cent. and 8.5 per cent., respectively, the puddled metal gains from 9 to 36 per cent., by the addition of a quantity of phosphorus sufficient to reduce the oxides, while there remains in the alloy only a trace of phosphorus.

CONCLUSIONS UPON THE USE OF ORDINARY BRONZE FOR CANNON.

It results from a summary of the trials with ordinary bronze, that the temperature of the casting, and the method of cooling, have a very great influence on the qualities of the alloy.

1st. Slow cooling should be avoided whenever circumstances permit it, not only because it assists the liquation, but also diminishes the strength very much.

2d. In adopting the plan of quick cooling, our trials demonstrate that the most favorable temperature for casting is that which we have called the mean; that is, about 1500° C. to 1600° C.

Old cannon-bronze, or new bronze, recast in the open air, absorbs oxygen, which combines with the tin to form an oxide in solution, to the great detriment of the strength of the metal. Puddling very imperfectly separates these oxides.

The greatest strength of ordinary bronze can only be obtained by the addition of a reductive powerful enough to eliminate all the oxygen; and it is not improbable that this is the true explanation of the superiority of the cannon cast by the brothers Keller, during the reign of Louis XIV—a superiority recognized, but the causes of which have been, until now, sought for without success, although the analysis has shown the presence of zinc in the pieces cast by these founders.

3d. If, owing to particular circumstances, one is obliged to use the method of slow cooling, it will be better to employ old bronze, because the presence of the oxide in solution partially prevents liquation; and to make the casting at the lowest possible temperature, because by this manner of *cooling* we obtain the greatest strength.

BINARY ALLOYS OF COPPER AND MANGANESE.

TRIALS OF LIQUATION.

A trial of liquation, made with 4 kilogrammes of an alloy of 20 per cent. of manganese and 80 per cent. of copper, gave the following result:

The solidified part in the crucible contained 18.39 per cent. of manganese and 81.61 per cent. of copper.

The portion run off 19.85 per cent. of manganese and 80.15 per cent. of copper.

It would seem from this result that, in cooling, the mixture had separated into alloys having different proportions of manganese. This is, however, not proven; for the portion of the solidified part, having less manganese, may proceed from partial oxidation of this metal, which oxidizes much easier than copper, and this oxidation ought to be hastened in the solidified part, which, during a certain time, is at a red heat, and in a spongy state.

Alloys of copper and manganese, even with a large proportion of the latter metal, offer no difficulty in casting, and the proof-bars, almost without exception, show no flaws. On the other hand, it is hardly possible to obtain these alloys with a constant composition, and this is on account of the unequal oxidability of the constituent metals, of which we have spoken. In all the alloys of this kind which we have tried, each fusion of metal causes a diminution of $\frac{1}{2}$ to 1 per cent. in the quantity of manganese, so that, in an alloy with 10 per cent. of manganese, a single fusion sufficed to diminish 10 per cent. the proportion of this metal.

TERNARY ALLOYS OF COPPER, TIN, AND MANGANESE.

The foregoing remarks as to the binary alloys containing manganese apply equally well to the ternary alloys.

ALLOY

OF 5 PER CENT. MANGANESE AND 95 PER CENT. COPPER.

No. 10.

THE ANALYSIS OF THE BAR GAVE:

4.42 manganese.

95.71 copper.

Total, 100.13

The bar was cast at 1615°C. , in an ingot-mold heated red.

Specific gravity of the turned bar.....	8.668
Specific gravity of sample from bottom of bar.....	8.721
Specific gravity of sample from top of bar.....	8.766

The bar, therefore, contained—

1.13 PER CENT. OF CAVITIES AND 98.87 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.766.

The trial under the hydraulic press gave:

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of bar at point of rupture.....	1.03 inches.
Section of bar at point of rupture.....	0.833 square inch.
Contraction of the section.....	16.7 per cent.
Final permanent elongation.....	6.8 per cent.

We obtained, also, with a mixture of 5 per cent. of manganese and 95 per cent. of copper, cast at 1615°C. , in an ingot-mold heated red:

An *elastic* resistance of 10,400 pounds per square inch, or **731** kilogrammes per square centimetre.

An *absolute* resistance of the original section of 19,524 pounds, or **1,372** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 23,438 pounds, or **1,647** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

MANGANESIFEROUS COPPER.

No. 10.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.011	
5,500	0.012	
6,000	0.014	
6,500	0.016	
7,000	0.018	
7,500	0.020	
8,000	0.022	
8,500	0.024	
9,000	0.026	
9,500	0.029	
10,000	0.032	0.008
10,500	0.037	
11,000	0.042	
11,500	0.051	
12,000	0.068	0.040
12,500	0.079	
13,000	0.102	
13,500	0.130	
14,000	0.161	0.128
14,500	0.185	
15,000	0.220	
15,500	0.262	
16,000	0.295	0.258
16,500	0.322	
17,000	0.373	
17,500	0.418	
18,000	0.462	0.424
18,500	0.505	
19,000	0.573	
19,500	0.665	
19,524	Rupture.	0.680

ALLOY

OF 10 PER CENT. OF MANGANESE AND 90 PER CENT. COPPER.

No. 11.

THE ANALYSIS OF THE BAR GAVE:

9.22 manganese.
 90.50 copper.

Total, 99.72

The bar was cast at 1622°C. , in an ingot-mold heated red.

The specific gravity of the turned bar was..... 8.492

The specific gravity of sample from top of bar..... 8.595

The specific gravity of sample from bottom of bar..... 8.630

The bar, therefore, contained—

1.60 PER CENT. OF CAVITIES AND 98.40 PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF 8.630.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.02 inches.
Section of bar at point of rupture.....	0.817 square inch.
Contraction of section.....	18.3 per cent.
Final permanent elongation.....	8.3 per cent.

We obtained, also, with an alloy of 10 per cent. of manganese and 90 per cent. of copper, cast at 1622°C. , in an ingot-mold heated red:

An *elastic* resistance of 15,400 pounds per square inch, or **1,082** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 26,582 pounds, or **1,868** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 32,536 pounds, or **2,287** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

MANGANESIFEROUS COPPER.

No. 11.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010	
5,500	0.011	
6,000	0.012	
6,500	0.014	
7,000	0.016	
7,500	0.018	
8,000	0.020	
8,500	0.021	
9,000	0.022	
9,500	0.023	
10,000	0.025	0.000
10,500	0.027	
11,000	0.029	
11,500	0.030	
12,000	0.031	0.003
12,500	0.032	
13,000	0.033	
13,500	0.035	
14,000	0.037	0.006
14,500	0.040	
15,000	0.042	
15,500	0.052	
16,000	0.062	0.031
16,500	0.073	
17,000	0.080	
17,500	0.100	
18,000	0.132	0.093
18,500	0.153	
19,000	0.188	
19,500	0.229	
20,000	0.263	0.221
20,500	0.287	
21,000	0.331	
21,500	0.364	
22,000	0.408	
22,500	0.444	
23,000	0.482	
23,500	0.528	
24,000	0.580	
24,500	0.610	
25,000	0.660	
25,500	0.692	
26,000	0.740	
26,500	0.788	
26,582	Rupture.	0.830

ALLOY

OF 5 PER CENT. OF MANGANESE, 5 PER CENT. OF TIN, AND 90 PER CENT. OF COPPER.

No. 12.

THE ANALYSIS OF THE BAR GAVE:

4.63 manganese.

4.96 tin.

89.71 copper.

Total, 99.30

The bar was cast at **1433° C.**, in a cold ingot-mold.

The specific gravity of the turned bar was..... 8.570

The specific gravity of sample from bottom of bar..... 8.817

The specific gravity of sample from top of bar..... 8.804

The bar, therefore, contained—

2.81 PER CENT. OF CAVITIES AND **97.19** PER CENT. OF METAL WITH A SPECIFIC GRAVITY OF **8.817**.

The result of the trial under the hydraulic press gave :

Original diameter of the bar..... 1.128 inches.

Original section of the bar..... 1 square inch.

Original length of the bar..... 10 inches.

Diameter of the bar at point of rupture..... 1.08 inches.

Section of bar at point of rupture..... 0.916 square inch.

Contraction of section..... 8.4 per cent.

Final permanent elongation..... 1.8 per cent.

We obtained also, for an alloy of 5 per cent. of manganese, 5 per cent. of tin, and 90 per cent. of copper, cast at **1433° C.**, in a cold ingot-mold :

An *elastic* resistance of 14,700 pounds per square inch, or **1,033** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 19,494 pounds, or **1,360** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 21,282 pounds, or **1,496** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

MANGANESIFEROUS BRONZE.

No. 12.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010	
5,500	0.011	
6,000	0.012	
6,500	0.015	
7,000	0.018	
7,500	0.020	
8,000	0.021	
8,500	0.023	
9,000	0.024	
9,500	0.026	
10,000	0.028	0.000
10,500	0.030	
11,000	0.031	
11,500	0.032	
12,000	0.034	0.003
12,500	0.037	
13,000	0.039	
13,500	0.041	
14,000	0.042	0.007
14,500	0.044	
15,000	0.049	
15,500	0.053	
16,000	0.060	0.027
16,500	0.071	
17,000	0.079	
17,500	0.096	
18,000	0.114	0.072
18,500	0.142	
19,000	0.178	
19,494	Rupture.	0.180

ALLOY

OF 5 PER CENT. MANGANESE, 10 PER CENT. TIN, AND 85 PER CENT.
OF COPPER.

No. 13.

THE ANALYSIS OF THE BAR GAVE:

4.72 manganese.
10.09 tin.
84.80 copper.

Total, 99.61

The bar was cast at 1517°C. , in a cold ingot-mold.

Specific gravity of the turned bar.....	8.618
Specific gravity of sample from bottom of bar.....	8.804
Specific gravity of sample from top of bar.....	8.799

The bar, therefore, contained—

2.11 PER CENT. OF CAVITIES AND 97.89 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.804.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.09 inches.
Section of bar at point of rupture.....	0.933 square inch.
Contraction of the section.....	6.7 per cent.
Final permanent elongation.....	1.7 per cent.

We obtained, also, with a mixture of 5 per cent. of manganese, 10 per cent. of tin, and 85 per cent. of copper, cast at 1517°C. , in a cold mold:

An *elastic* resistance of 19,900 pounds per square inch, or 1,402 kilogrammes per square centimetre.

An *absolute* resistance of the original section of 28,376 pounds, or 1,995 kilogrammes per square centimetre.

An *absolute* resistance, at point of rupture, of 30,413 pounds, or 2,140 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

MANGANESIFEROUS BRONZE.

No. 13.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.011		17,000	0.046	
5,500	0.013		17,500	0.048	
6,000	0.015		18,000	0.050	0.008
6,500	0.017		18,500	0.051	
7,000	0.019		19,000	0.052	
7,500	0.020		19,500	0.052	
8,000	0.021		20,000	0.056	0.013
8,500	0.022		20,500	0.058	
9,000	0.023		21,000	0.061	
9,500	0.025		21,500	0.064	
10,000	0.027	0.000	22,000	0.068	0.022
10,500	0.028		22,500	0.072	
11,000	0.030		23,000	0.076	
11,500	0.031		23,500	0.080	
12,000	0.032	0.001	24,000	0.088	0.038
12,500	0.033		24,500	0.093	
13,000	0.035		25,000	0.100	
13,500	0.036		25,500	0.108	
14,000	0.038	0.004	26,000	0.113	0.060
14,500	0.039		26,500	0.122	
15,000	0.040		27,000	0.132	
15,500	0.041		27,500	0.141	
16,000	0.043	0.007	28,000	0.152	
16,500	0.045		28,376	Rupture.	0.170

ALLOY

OF 10 PER CENT. OF MANGANESE, 10 PER CENT. OF TIN, AND 80 PER CENT. OF COPPER.

No. 14.

THE ANALYSIS OF THE BAR GAVE:

9.39 manganese.
9.81 tin.
80.23 copper.

Total, 99.43

The bar was cast at 1672°C. , in a cold ingot-mold.

The specific gravity of the turned bar was..... 8.453
The specific gravity of a specimen from bottom of bar..... 8.606
The specific gravity of a specimen from top of bar..... 8.605

The bar, therefore, contained—

1.78 PER CENT. OF CAVITIES AND 98.22 PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF 8.606.

The trial under the hydraulic press gave the following:

Original diameter of bar..... 1.128 inches.
Original section of bar..... 1 square inch.
Original length of bar..... 10 inches.
Diameter of bar at point of rupture..... 1.12 inches.
Section of bar at point of rupture..... 0.985 square inch.
Contraction of section..... 1.5 per cent.
Final permanent elongation..... 0.6 per cent.

We also obtained, with an alloy of 10 per cent. of manganese, 10 per cent. of tin, and 80 per cent. of copper, cast at 1672°C. , in a cold ingot-mold:

An *elastic* resistance of 28,100 pounds per square inch, or 1,975 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 31,840 pounds, or 2,240 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 32,325 pounds, or 2,275 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

MANGANESIFEROUS BRONZE.

No. 14.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.011		18,000	0.044	0.004
5,500	0.013		18,500	0.045	
6,000	0.015		19,000	0.046	
6,500	0.017		19,500	0.047	
7,000	0.018		20,000	0.048	0.005
7,500	0.019		20,500	0.049	
8,000	0.021		21,000	0.050	
8,500	0.022		21,500	0.050	
9,000	0.023		22,000	0.051	0.005
9,500	0.025		22,500	0.052	
10,000	0.027	0.000	23,000	0.053	
10,500	0.029		23,500	0.054	
11,000	0.030		24,000	0.056	0.005
11,500	0.031		24,500	0.057	
12,000	0.032	0.000	25,000	0.058	
12,500	0.033		25,500	0.059	
13,000	0.034		26,000	0.060	0.006
13,500	0.035		26,500	0.061	
14,000	0.036	0.002	27,000	0.062	
14,500	0.037		27,500	0.063	
15,000	0.038		28,000	0.064	0.009
15,500	0.039		28,500	0.068	
16,000	0.040	0.003	29,000	0.070	
16,500	0.041		29,500	0.071	
17,000	0.042		30,000	0.072	0.012
17,500	0.043		31,840	Rupture.	0.060

CONCLUSIONS ON THE USE OF MANGANESE.

From the summary of these trials, it is evident that the use of this metal, whether in binary combinations or in ternary compositions, should be completely discarded. It has the effect of increasing the hardness and elasticity of ordinary cannon-bronze; but, without taking into consideration its high price, it has the effect of diminishing the tenacity of the alloys, and to produce such irregularities in the composition as that its use would create a constant uncertainty as to the resistance.

BINARY ALLOYS OF COPPER AND NICKEL.

TRIAL OF LIQUATION.

First trial.—In fusing and cooling 5 kilogrammes of an alloy of $4\frac{1}{2}$ per cent. of nickel, in the manner described above, we have obtained the following results:

The solidified part in the crucible had a specific gravity of 8.895, and contained 4.479 per cent. of nickel and 95.730 per cent. of copper.

The part of the mixture run off had a specific gravity of 8.863, and contained 4.495 per cent. of nickel and 95.795 per cent. of copper.

Second trial.—In a similar operation, with 5 kilogrammes of an alloy of 20 per cent. of nickel, we obtained the following:

The part solidified in the crucible had a specific gravity of 8.927, and contained 20.869 per cent. of nickel and 80.141 per cent. of copper.

The part of the alloy run off had a specific gravity of 8.910, and contained 20.627 per cent. of nickel and 80.141 per cent. of copper.

These trials establish the point that alloys of copper and nickel do not suffer a sensible liquation by slow cooling. But, on the other hand, the absorption of oxygen by the metal while in fusion is observed, in these alloys, in a higher degree than with pure copper, and this absorption increases with the temperature of the bath and its content of nickel.

If a crucible half filled with an alloy of 80 per cent. of nickel and 20 per cent. of copper is heated to a white heat, and submitted to a quick cooling, in setting the crucible upon a lining-plate of the priming-hearth, the gas is disengaged with such intensity that the metal overflows.

We have cast an enormous quantity of proof-bars, from alloys of all proportions, from 5 to 20 per cent. of nickel, observing all possible conditions of temperature in casting and in the mode of cooling, adding now and then a small quantity of zinc, for the purpose of absorbing the oxygen gas, if any was held in the mixture, of which there was very little doubt; but it has been absolutely impossible for us to obtain a single bar, fit for the trial of resistance, having a proportion greater than 10 per cent. of nickel.

Often we have established a difference of more than 10 per cent. between the specific gravity of a bar and that of the alloy from which it was made.

Below 10 per cent. we have been able to obtain compact bars by casting at a low temperature and slowly cooling in the mold; that is to say, by heating the mold to a red heat.

Compact bars can always be obtained with a mixture containing a small proportion of nickel, by adding to the bath, a few moments before casting, about one-half per cent. of zinc. This metal is eliminated in the state of an oxide, which floats on the surface of the bath, and, if it has been introduced in a proper quantity, no trace of it is shown in the analysis, which demonstrates that it is the oxygen that is absorbed.

ALLOY

OF 5 PER CENT. OF NICKEL AND 95 PER CENT. OF COPPER.

No. 15.

THE ANALYSIS OF THE BAR GAVE:

4.84 nickel.
 95.02 copper.

Total, 99.86

The bar had been cast with an addition of one-half per cent. of zinc, in an ingot-mold heated red.

The temperature of the metallic bath, at the moment of casting, was **1692° C.**

Specific gravity of the turned bar.....	8.662
Specific gravity of specimen from bottom of bar.....	8.879
Specific gravity of specimen from top of bar.....	8.942

The bar, therefore, contained—

3.13 PER CENT. OF CAVITIES AND **96.87** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **.942**.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at the point of rupture.....	0.960 inch.
Section of bar at the point of rupture.....	0.724 square inch.
Contraction of the section.....	27.6 per cent.
Final permanent elongation.....	14.7 per cent.

We obtained, also, with an alloy of 5 per cent. of nickel and 95 per cent. of copper, cast at 1692° C., in a heated mold:

An *elastic* resistance less than 10,000 pounds per square inch, or **703** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 23,792 pounds, or **1,682** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 33,110 pounds, or **2,325** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

COPPER AND NICKEL.

No. 15.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.220	0.195
10,500	0.242	
11,000	0.270	
11,500	0.302	
12,000	0.332	0.305
12,500	0.368	
13,000	0.400	
13,500	0.433	
14,000	0.472	0.440
14,500	0.503	
15,000	0.542	
15,500	0.584	
16,000	0.629	0.591
16,500	0.668	
17,000	0.706	
17,500	0.760	
18,000	0.800	0.776
18,500	0.846	
19,000	0.880	
19,500	0.948	
20,000	1.000	0.970
20,500	1.030	
21,000	1.080	
21,500	1.150	
22,000	1.260	1.240
22,500	1.290	
23,000	1.320	
23,500	1.400	
23,972	Rupture.	1.470

ALLOY

OF 10 PER CENT. OF NICKEL AND 90 PER CENT. OF COPPER.

No. 16.

ANALYSIS OF THE BAR GAVE :

10.16 nickel.
89.30 copper.

Total, **99.46**

The bar had been cast at **1760° C.**, in an ingot-mold heated red, with an addition of one-third per cent. of zinc before casting.

Specific gravity of the bar was.....	8.625
Specific gravity of sample from top of bar.....	8.982
Specific gravity of sample from bottom of bar.....	8.973

The bar, therefore, contained—

3.88 PER CENT. OF CAVITIES AND **96.12** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.973**.

The trial under the hydraulic press gave :

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	0.97 inch.
Section of bar at point of rupture.....	0.739 square inch.
Contraction of section.....	26.1 per cent.
Final permanent elongation.....	15.6 per cent.

We obtained, also, with a mixture of 10 per cent. of nickel and 90 per cent. of copper, cast at 1760° C., in a heated mold :

An *elastic* resistance of 7,400 pounds per square inch, or **520** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 26,012 pounds, or **1,830** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 35,199 pounds, or **2,472** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

COPPER AND NICKEL.

No. 16.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010	
5,500	0.013	
6,000	0.016	
6,500	0.020	
7,000	0.025	
7,500	0.035	
8,000	0.050	0.029
8,500	0.061	
9,000	0.088	
9,500	0.108	
10,000	0.132	0.109
10,500	0.163	
11,000	0.188	
11,500	0.211	
12,000	0.244	0.203
12,500	0.272	
13,000	0.302	
13,500	0.334	
14,000	0.368	0.332
14,500	0.400	
15,000	0.437	
15,500	0.465	
16,000	0.508	0.462
16,500	0.557	
17,000	0.588	
17,500	0.622	
18,000	0.654	0.606
18,500	0.703	
19,000	0.742	
19,500	0.781	
20,000	0.824	0.762
20,500	0.873	
21,000	0.914	
21,500	0.960	
22,000	1.010	0.950
22,500	1.070	
23,000	1.140	
23,500	1.210	
24,000	1.250	1.190
24,500	1.300	
25,000	1.370	
25,500	1.460	
26,000	1.550	
26,012	Rupture.	1.560

TERNARY ALLOYS OF COPPER, TIN, AND NICKEL.

TRIALS OF LIQUATION.

In fusing and cooling 8 kilogrammes of a mixture of $82\frac{1}{2}$ per cent. of copper, 10 per cent. of nickel, and $7\frac{1}{2}$ per cent. of tin, we have obtained the following results:

The solidified part contained.....	6.53 per cent. tin.
The part run off contained.....	7.98 per cent. tin.

It results from this trial that ternary alloys, with the addition of nickel, undergo, like ordinary bronze, a liquation by slow cooling.

Our preceding trials with ordinary bronze having demonstrated that the most favorable conditions for casting alloys which undergo a liquation were to cast at a mean temperature, and cool quickly, all the trials of ternary alloys with nickel were made under these conditions.

ALLOY

OF 5 PER CENT. NICKEL, 5 PER CENT. TIN, AND 90 PER CENT. COPPER.

No. 17.

THE ANALYSIS OF THE BAR GAVE:

5.16 tin.
 4.89 nickel.
 89.80 copper.

 Total, 99.85
The bar was cast at 1700°C. , in a cold ingot-mold.

The specific gravity of the turned bar was 8.760
 The specific gravity of a specimen from bottom of bar 8.916
 The specific gravity of a specimen from top of bar 8.947

The bar, therefore, contained—

2.11 PER CENT. OF CAVITIES AND **97.89** PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF **8.947**.

The trial under the hydraulic press gave:

Original diameter of bar 1.128 inches.
 Original section of bar 1 square inch.
 Original length of bar 10 inches.
 Diameter of bar at point of rupture 0.100 inch.
 Section of bar at point of rupture 0.785 square inch.
 Contraction of the section 21.5 per cent.
 Final permanent elongation 7.2 per cent.

We also obtained, with a mixture of 5 per cent. of nickel, 5 per cent. of tin, and 90 per cent. of copper, cast at 1700°C. , in a cold ingot-mold:An *elastic* resistance of 15,900 pounds per square inch, or **1,118** kilogrammes per square centimetre.An *absolute* resistance with the original section of 28,044 pounds, or **1,972** kilogrammes per square centimetre.An *absolute* resistance, at the point of rupture, of 35,724 pounds, or **2,518** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

NICKELIFEROUS BRONZE.

No. 17.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010		17,000	0.060	
5,500	0.011		17,500	0.066	
6,000	0.012		18,000	0.079	0.042
6,500	0.014		18,500	0.088	
7,000	0.016		19,000	0.102	
7,500	0.018		19,500	0.122	
8,000	0.019		20,000	0.143	0.100
8,500	0.020		20,500	0.168	
9,000	0.021		21,000	0.184	
9,500	0.022		21,500	0.215	
10,000	0.024	0.000	22,000	0.245	
10,500	0.026		22,500	0.272	
11,000	0.028		23,000	0.298	
11,500	0.029		23,500	0.327	
12,000	0.031	0.006	24,000	0.364	
12,500	0.032		24,500	0.391	
13,000	0.034		25,000	0.428	
13,500	0.036		25,500	0.470	
14,000	0.038	0.009	26,000	0.522	
14,500	0.039		26,500	0.564	
15,000	0.041		27,000	0.602	
15,500	0.044		27,500	0.644	
16,000	0.051	0.020	28,000	0.712	
16,500	0.054		28,044	Rupture.	0.720

ALLOY

OF 5 PER CENT. OF TIN, 10 PER CENT. OF NICKEL, AND 85 PER CENT.
OF COPPER.

No. 18.

THE ANALYSIS OF THE BAR GAVE:

10.23 nickel.

5.09 tin.

85.05 copper.

Total, **100.37**

The bar was cast at **1737° C.**, in a cold ingot-mold.

Specific gravity of the turned bar..... 8.620

Specific gravity of sample from bottom of bar..... 8.949

Specific gravity of sample from top of bar..... 8.963

The bar, therefore, contained—

3.83 PER CENT. OF CAVITIES AND **96.17** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.963**.

The trial under the hydraulic press gave:

Original diameter of the bar..... 1.128 inches.

Original section of the bar..... 1 square inch.

Original length of the bar..... 10 inches.

Diameter of bar at point of rupture..... 1.04 inches.

Section of bar at point of rupture..... 0.849 square inch.

Contraction of section..... 15.1 per cent.

Final permanent elongation..... 9.7 per cent.

We also obtained, with an alloy of 10 per cent. of nickel, 5 per cent.
of tin, and 85 per cent. of copper, cast at 1737° C., in a cold ingot-mold:

An *elastic* resistance of 18,900 pounds per square inch, or **1,334** kilo-
grammes per square centimetre.

An *absolute* resistance with the original section of 37,728 pounds, or **2,665**
kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 44,438 pounds, or **3,140**
kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

NICKELIFEROUS BRONZE.

No. 18.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010		18,000	0.052	0.010
5,500	0.011		18,500	0.054	
6,000	0.012		19,000	0.062	
6,500	0.014		19,500	0.068	
7,000	0.016		20,000	0.071	0.032
7,500	0.018		20,500	0.077	
8,000	0.020		21,000	0.086	
8,500	0.021		21,500	0.093	
9,000	0.022		22,000	0.102	0.053
9,500	0.023		22,500	0.112	
10,000	0.025	0.000	23,000	0.128	
10,500	0.027		23,500	0.140	
11,000	0.029		24,000	0.158	0.097
11,500	0.030		24,500	0.174	
12,000	0.031	0.001	25,000	0.191	
12,500	0.032		25,500	0.220	
13,000	0.033		26,000	0.238	
13,500	0.034		26,500	0.260	
14,000	0.036	0.003	27,000	0.273	
14,500	0.038		27,500	0.294	
15,000	0.040		28,000	0.318	
15,500	0.041		28,500	0.341	
16,000	0.043	0.007	29,000	0.364	
16,500	0.045		29,500	0.398	
17,000	0.048		30,000	0.419	
17,500	0.050		37,728	Rupture.	0.970

ALLOY

OF 20 PER CENT. OF NICKEL, 5 PER CENT. OF TIN, AND 75 PER CENT.
OF COPPER.

No. 19.

THE ANALYSIS OF THE BAR GAVE:

20.52 nickel.
5.13 tin.
74.58 copper.

Total, 100.23

The bar was cast at 1749° C., in a cold ingot-mold.

Specific gravity of the turned bar.....	8.747
Specific gravity of sample from bottom of bar.....	8.859
Specific gravity of sample from top of bar.....	8.926

The bar, therefore, contained—

2.01 PER CENT. OF CAVITIES AND 97.99 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.926.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.07 inches.
Section of bar at point of rupture.....	0.899 square inch.
Contraction of the section.....	10.1 per cent.
Final permanent elongation.....	3.8 per cent.

We also obtained, with an alloy of 20 per cent. of nickel, 5 per cent. of tin, and 75 per cent. of copper, cast at 1749° C., in a cold ingot-mold:

An *elastic* resistance of 20,400 pounds per square inch, or 1,440 kilogrammes per square centimetre.

An *absolute* resistance of the original section of 31,472 pounds, or 2,220 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 35,008 pounds, or 2,470 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

NICKELIFEROUS BRONZE.

No. 19.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.012		18,000	0.046	0.005
5,500	0.013		18,500	0.047	
6,000	0.015		19,000	0.049	
6,500	0.017		19,500	0.050	
7,000	0.019		20,000	0.051	0.007
7,500	0.020		20,500	0.055	
8,000	0.021*		21,000	0.059	
8,500	0.022		21,500	0.062	
9,000	0.023		22,000	0.068	0.023
9,500	0.024		22,500	0.073	
10,000	0.025	0.000	23,000	0.080	
10,500	0.027		23,500	0.088	
11,000	0.028		24,000	0.098	0.048
11,500	0.029		24,500	0.107	
12,000	0.030	0.001	25,000	0.116	
12,500	0.031		25,500	0.128	
13,000	0.032		26,000	0.146	0.092
13,500	0.033		26,500	0.160	
14,000	0.034	0.002	27,000	0.175	
14,500	0.036		27,500	0.192	
15,000	0.037		28,000	0.201	0.160
15,500	0.038		28,500	0.240	
16,000	0.040	0.003	29,000	0.261	
16,500	0.041		29,500	0.281	
17,000	0.043		30,000	0.313	0.252
17,500	0.045		31,472	Rupture.	0.380

ALLOY

OF 5 PER CENT. NICKEL, 10 PER CENT. TIN, AND 85 PER CENT. COPPER.

No. 20.

THE ANALYSIS OF THE BAR GAVE:

5.09 nickel.
 9.88 tin.
 84.64 copper.

Total, 99.61

The bar was cast at 1656°C. , in a cold ingot-mold.

Specific gravity of the turned bar..... 8.727
 Specific gravity of sample from bottom of bar..... 8.950
 Specific gravity of sample from top of bar..... 8.966

The bar, therefore, contained—

2.66 PER CENT. OF CAVITIES AND 97.34 PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF 8.966.

The trial under the hydraulic press gave:

Original diameter of bar..... 1.128 inches.
 Original section of bar..... 1 square inch.
 Original length of bar..... 10 inches.
 Diameter of bar at point of rupture..... 1.11 inches.
 Section of bar at point of rupture..... 0.967 square inch.
 Contraction of section..... 3.3 per cent.
 Final permanent elongation..... 1 per cent.

We also obtained, with an alloy of 5 per cent. of nickel, 10 per cent. of tin, and 85 per cent. of copper, cast at 1656°C. , in a cold ingot-mold:

An *elastic* resistance of 17,900 pounds per square inch, or 1,263 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 22,950 pounds, or 1,621 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 23,737 pounds, or 1,677 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

NICKELIFEROUS BRONZE.

No. 20.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010	
5,500	0.011	
6,000	0.013	
6,500	0.015	
7,000	0.017	
7,500	0.019	
8,000	0.020	
8,500	0.021	
9,000	0.022	
9,500	0.023	
10,000	0.025	0.000
10,500	0.027	
11,000	0.029	
11,500	0.030	
12,000	0.031	0.003
12,500	0.032	
13,000	0.033	
13,500	0.034	
14,000	0.035	0.004
14,500	0.037	
15,000	0.039	
15,500	0.040	
16,000	0.041	0.008
16,500	0.042	
17,000	0.044	
17,500	0.046	
18,000	0.050	0.014
18,500	0.052	
19,000	0.054	
19,500	0.057	
20,000	0.062	0.025
20,500	0.068	
21,000	0.072	
21,500	0.080	
22,000	0.091	0.060
22,500	0.102	
22,954	Rupture.	0.100

ALLOY

OF 10 PER CENT. NICKEL, 10 PER CENT. TIN, AND 80 PER CENT. OF
COPPER.

No. 21.

THE ANALYSIS OF THE BAR GAVE:

9.86 nickel.
10.12 tin.
80.20 copper.

Total, 100.18

The bar was cast at 1626°C. , in a cold ingot-mold.

The specific gravity of the bar was..... 8.741
The specific gravity of sample from bottom of bar..... 8.951
The specific gravity of sample from top of bar..... 9.005

The bar, therefore, contained—

2.94 PER CENT. OF CAVITIES AND 97.06 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 9.005.

The result of the trial under the hydraulic press:

Original diameter of the bar was..... 1.128 inches.
Original section of the bar was..... 1 square inch.
Original length of the bar was..... 10 inches.
Diameter of bar at point of rupture..... 1.12 inches.
Section of bar at point of rupture..... 0.985 square inch.
Contraction of the section..... 1.5 per cent.
Final permanent elongation..... 1.1 per cent.

We also obtained, with an alloy of 10 per cent. nickel, 10 per cent. of tin, and 80 per cent. of copper, cast at 1626°C. , in a cold ingot-mold:

An *elastic* resistance of 22,200 pounds per square inch, or 1,568 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 28,788 pounds, or 2,032 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 29,125 pounds, or 2,055 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

NICKELIFEROUS BRONZE.

No. 21.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010		17,500	0.041	
5,500	0.011		18,000	0.042	0.004
6,000	0.012		18,500	0.043	
6,500	0.013		19,000	0.044	
7,000	0.015		19,500	0.045	
7,500	0.017		20,000	0.047	0.007
8,000	0.019		20,500	0.049	
8,500	0.020		21,000	0.051	
9,000	0.021		21,500	0.052	
9,500	0.022		22,000	0.053	0.010
10,000	0.024	0.000	22,500	0.058	
10,500	0.026		23,000	0.060	
11,000	0.028		23,500	0.062	
11,500	0.029		24,000	0.068	0.021
12,000	0.030	0.000	24,500	0.072	
12,500	0.031		25,000	0.075	
13,000	0.032		25,500	0.080	
13,500	0.033		26,000	0.090	0.040
14,000	0.034	0.001	26,500	0.098	
14,500	0.035		27,000	0.105	
15,000	0.036		27,500	0.111	
15,500	0.037		28,000	0.124	0.067
16,000	0.038	0.002	28,500	0.149	
16,500	0.039		28,788	Rupture.	0.110
17,000	0.040				

CONCLUSIONS UPON THE USE OF NICKEL.

A review of these trials shows—

1st. That nickel cannot be employed in a binary alloy with copper, because with less than 10 per cent. of nickel we cannot get sufficient hardness, and with more than 10 per cent. of nickel it is impossible to obtain a compact metal.

2d. That in ternary alloys of copper, tin, and nickel, the influence of this last metal is but little felt. It increases, in a certain degree, both the elastic and absolute resistance, but by no means in proportion to the increase which it causes in the price, while it has no sensible influence either on the liquation or on the hardness of metal.

* * * * *

TRIAL OF BRONZE WITH THE ADDITION OF IRON.

The following experiment shows that the addition of iron, without having any sensible effect on the strength of bronze, results in diminishing the hardness, and in producing irregularities in the curves of resistances, caused, no doubt, by the relative facility with which iron is oxidized, similar to that experienced with alloys containing manganese.

BRONZE

CONTAINING **85** PER CENT. OF COPPER, **10** PER CENT. OF TIN, AND
5 PER CENT. OF IRON.

No. 22.

THE ANALYSIS OF THE BAR GAVE:

4.98 iron.
9.81 tin.
85.04 copper.

Total, **99.83**

The bar was cast at **1680 C.**, in a cold ingot-mold.

Specific gravity of the turned bar was..... 8.610
Specific gravity of sample from bottom of bar..... 8.809
Specific gravity of sample from top of bar..... 8.743

The bar, therefore, contained—

2.28 PER CENT. OF CAVITIES AND **97.72** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.809**.

The trial under the hydraulic press gave:

Original diameter of bar..... 1.128 inches.
Original section of bar..... 1 square inch.
Original length of bar..... 10 inches.
Diameter of bar at point of rupture..... 1.09 inches.
Section of bar at point of rupture..... 0.933 square inch.
Contraction of section..... 6.7 per cent.
Final permanent elongation..... 2.9 per cent.

We also obtained, with an alloy of 5 per cent. of iron, 10 per cent. of tin, and 85 per cent. of copper, cast at 1680° C., in a cold ingot-mold:

An *elastic* resistance of 18,800 pounds per square inch, or **1,321** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 28,620 pounds, or **2,012** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 30,675 pounds, or **2,156** kilogrammes per square centimetre.

TRIAL OF RESISTANCE

FERRUGINOUS BRONZE.

No. 22.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.011		17,500	0.049	
5,500	0.012		18,000	0.051	0.010
6,000	0.014		18,500	0.052	
6,500	0.016		19,000	0.056	
7,000	0.018		19,500	0.059	
7,500	0.019		20,000	0.061	0.018
8,000	0.021		20,500	0.066	
8,500	0.022		21,000	0.070	
9,000	0.023		21,500	0.074	
9,500	0.025		22,000	0.080	0.032
10,000	0.027	0.000	22,500	0.088	
10,500	0.029		23,000	0.096	
11,000	0.030		23,500	0.108	
11,500	0.032		24,000	0.122	0.070
12,000	0.034	0.002	24,500	0.131	
12,500	0.036		25,000	0.147	
13,000	0.038		25,500	0.162	
13,500	0.039		26,000	0.179	0.120
14,000	0.039	0.004	26,500	0.191	
14,500	0.040		27,000	0.210	
15,000	0.041		27,500	0.228	
15,500	0.042		28,000	0.252	0.190
16,000	0.043	0.007	28,500	0.289	
16,500	0.045		28,620	Rupture.	0.290
17,000	0.047				

TRIAL OF BRONZE WITH THE ADDITION OF ZINC.

The addition of zinc to ordinary bronze has the effect of increasing its elastic and absolute resistance in a sufficiently great degree, as indicated in our theory concerning the reduction of the oxide of tin; but this reduction has also the simultaneous effect of rendering the metal softer; and, as with iron and manganese, it is noted that the elasticity diminishes rapidly.

BRONZE

CONTAINING **88** PER CENT. OF COPPER, **10** PER CENT. OF TIN, AND **2** PER CENT. OF ZINC.

No. 23.

THE ANALYSIS OF THE BAR GAVE :

2.16 zinc.
10.09 tin.
87.30 copper.

Total, **99.55**

The bar was cast at **1648° C.**, in a cold ingot-mold.

The specific gravity of the turned bar was..... **8.752**

The specific gravity of sample from bottom of bar..... **8.880**

The specific gravity of sample from top of bar..... **8.861**

The bar, therefore, contained—

1.44 PER CENT. OF CAVITIES AND **98.56** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.880**.

The trial under the hydraulic press gave :

Original diameter of the bar..... **1.128** inches.
Original section of the bar..... **1** square inch.
Original length of the bar..... **10** inches.
Diameter of the bar at point of rupture..... **1.09** inches.
Section of the bar at point of rupture..... **0.933** square inch.
Contraction of section..... **6.7** per cent.
Final permanent elongation..... **1.8** per cent.

We also obtained, with an alloy of 2 per cent. of zinc, 10 per cent. of tin, and 88 per cent. of copper, cast at 1648° C., in a cold mold :

An *elastic* resistance of 24,300 pounds per square inch, or **1,708** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 34,984 pounds, or **2,459** kilogrammes per square centimetre.

An *absolute* resistance, at the section of rupture, of 37,496 pounds, or **2,636** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

ZINCIFEROUS BRONZE.

No. 23.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.010		18,000	0.045	0.007
5,500	0.012		18,500	0.047	
6,000	0.014		19,000	0.048	
6,500	0.016		19,500	0.049	
7,000	0.018		20,000	0.050	0.009
7,500	0.020		20,500	0.051	
8,000	0.022		21,000	0.052	
8,500	0.024		21,500	0.052	
9,000	0.025		22,000	0.053	0.009
9,500	0.026		22,500	0.053	
10,000	0.027	0.000	23,000	0.054	
10,500	0.028		23,500	0.055	
11,000	0.029		24,000	0.056	0.011
11,500	0.030		24,500	0.060	
12,000	0.031	0.000	25,000	0.061	
12,500	0.032		25,500	0.062	
13,000	0.034		26,000	0.064	0.016
13,500	0.035		26,500	0.067	
14,000	0.037	0.003	27,000	0.070	
14,500	0.038		27,500	0.074	
15,000	0.039		28,000	0.079	0.028
15,500	0.040		28,500	0.082	
16,000	0.041	0.005	29,000	0.088	
16,500	0.042		29,500	0.092	
17,000	0.043		30,000	0.100	
17,500	0.044		34,984	Rupture.	0.180

COPPER AND PHOSPHORUS.

We have shown how, in the course of our experiments, we have been induced to add phosphorus to the alloys for the purpose of increasing the strength, while reducing the oxides which might be found in solution.

We were naturally forced by these experiments to note the effect of phosphorus itself upon the qualities of the metal, and our first experiments were made with the phosphoride of copper.

In our preliminary trials we produced this phosphoride of copper by introducing phosphorus into a crucible filled with turnings of copper heated to redness. But this operation presented certain difficulties, and we substituted a slower process of reduction in a mixture of four parts of the acid phosphate of lime with two parts of copper and one of charcoal. We have thus been able to obtain, easily, phosphorides containing from 8 to 14 per cent. of phosphorus. By the addition of these rich phosphorides to a greater or less proportion of copper, we obtained the desired content of phosphorides.

The phosphoride of copper, cast at either a high or low temperature, and cooled either slowly or quickly, gives always perfectly compact bars, so long as the proportion of phosphorus does not go beyond 2 per cent. It is, on the contrary, exceedingly difficult to obtain, under any conditions, compact bars with a greater proportion than 2 per cent. of phosphorus, on account of its volatilization, as shown by the following:

When a phosphoride of copper having a relatively large proportion of phosphorus was kept in fusion, bubbles were seen to disengage themselves from the bosom of the liquid mass, and burn on the surface with a slight explosion.

When a phosphorous copper, rich in phosphorus, is kept in fusion, this latter element volatilizes, and with as much more rapidity as the content of phosphorus is greater. When the fusion is made in open air, the formation of a very fusible scoria is observed on the surface; and this scoria, composed of phosphate of oxide of copper, shows that the elimination of phosphorus, under these conditions, occurs not only by volatilization, but also by oxidation. It is not so, however, when the melting is made under a covering of charcoal. A portion of copper, with 14 per cent. of phosphorus, having been melted many times, under a covering of 10 centimetres of char-

coal, after cooling showed no superficial scoria. But the analysis, made after each successive fusion, gave the following results:

The metal originally contained.....	14.30 per cent. of phosphorus.
The metal, after first fusion, contained.....	8.48 per cent. of phosphorus.
The metal, after second fusion, contained..	6.43 per cent. of phosphorus.
The metal, after third fusion, contained....	4.87 per cent. of phosphorus.
The metal, after fourth fusion, contained...	4.10 per cent. of phosphorus.
The metal, after fifth fusion, contained.....	3.22 per cent. of phosphorus.
The metal, after sixth fusion, contained....	2.04 per cent. of phosphorus.

Finally, in order to have a point for comparison, we have established the resistance of pure copper, in operating upon the same copper which has served us for the trial of phosphorides.

PURE COPPER.

No. 24.

The bar was cast at **1360° C.**, in an ingot-mold heated red.

Specific gravity of the turned bar was.....	8.416
Specific gravity of sample from top of the bar.....	8.760
Specific gravity of sample from bottom of the bar.....	8.742

The bar, therefore, contained—

3.93 PER CENT. OF CAVITIES AND **96.07** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.760**.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of the bar at point of rupture.....	1.11 inches.
Section of the bar at point of rupture.....	0.967 square inch.
Contraction of the section.....	3.30 per cent.
Final permanent elongation.....	1.8 per cent.

We obtained, also, for pure copper, cast at 1360° C., in an ingot-mold heated red:

An *elastic* resistance of 4,400 pounds per square inch, or **309** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 6,973 pounds, or **490** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 7,211 pounds, or **507** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PURE COPPER.

No. 24.

EFFORT OF TRACTION.	ELONGATION DURING TRACTION.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.031	0.020
5,500	0.055	
6,000	0.100	0.087
6,500	0.182	
6,973	Broke.	0.180

PHOSPHORIDE OF COPPER

WITH 0.696 PER CENT. OF PHOSPHORUS.

No. 25.

THE ANALYSIS OF THE BAR GAVE: **0.696** per cent. phosphorus.

The bar was cast at **1602° C.**, in an ingot-mold heated red.

Specific gravity of the turned bar was.....	8.729
Specific gravity of sample from top of bar.....	8.864
Specific gravity of sample from bottom of bar.....	8.870

The bar, therefore, contained—

1.59 PER CENT. OF CAVITIES AND **98.41** PER CENT. OF METAL THE SPECIFIC GRAVITY OF WHICH WAS **8.870**.

The trial under the hydraulic press gave:

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of bar at point of rupture.....	0.92 inch.
Section of bar at point of rupture.....	0.665 square inch.
Contraction of section.....	33.5 per cent.
Final permanent elongation.....	23.8 per cent.

We also obtained, with a phosphoride of copper containing 0.696 per cent. of phosphorus, cast at 1602° C., in an ingot-mold heated red:

An *elastic* resistance of 6,600 pounds per square inch, or **466** kilogrammes per square centimetre.

An *absolute* resistance of the original section of 31,832 pounds, or **2,245** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 47,869 pounds, or **3,365** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS COPPER.

No. 25.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.015		18,000	0.602	0.544
5,500	0.018		18,500	0.634	
6,000	0.022	0.003	19,000	0.680	
6,500	0.025		19,500	0.722	
7,000	0.038		20,000	0.753	0.708
7,500	0.054		20,500	0.792	
8,000	0.063	0.043	21,000	0.840	
8,500	0.085		21,500	0.890	
9,000	0.102		22,000	0.930	0.880
9,500	0.123		22,500	0.974	
10,000	0.147	0.120	23,000	1.020	
10,500	0.169		23,500	1.070	
11,000	0.190		24,000	1.130	1.060
11,500	0.212		24,500	1.190	
12,000	0.240	0.202	25,000	1.250	
12,500	0.264		25,500	1.300	
13,000	0.290		26,000	1.350	1.280
13,500	0.318		26,500	1.400	
14,000	0.345	0.310	27,000	1.470	
14,500	0.378		27,500	1.550	
15,000	0.400		28,000	1.610	1.550
15,500	0.432		28,500	1.660	
16,000	0.470	0.429	29,000	1.760	
16,500	0.508		29,500	1.870	
17,000	0.540		30,000	1.970	1.900
17,500	0.578		31,832	Rupture.	2.380

PHOSPHORIDE OF COPPER

WITH **1.292** PER CENT. OF PHOSPHORUS.

No. 26.

THE ANALYSIS OF THE BAR GAVE: **1,292** per cent. of phosphorus.

The bar was cast at **1572° C.**, in an ingot-mold heated red:

The specific gravity of the turned bar was.....	8.590
The specific gravity of sample from top of bar.....	8.739
The specific gravity of sample from bottom of bar.....	8.688

The bar, therefore, contained—

1.71 PER CENT. OF CAVITIES AND **98.29** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.739**.

The trial under the hydraulic press gave:

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of bar at point of rupture.....	0.99 inch.
Section of bar at point of rupture.....	0.770 square inch.
Contraction of section.....	23.0 per cent.
Final permanent elongation.....	24.7 per cent.

We obtained, also, with a phosphoride of copper containing 1.292 per cent. of phosphorus, cast at 1572° C., in an ingot-mold heated red:

An *elastic* resistance of 9,700 pounds per square inch, or **682** kilogrammes per square centimetre.

An *absolute* resistance with the primitive section of 39,896 pounds, or **2,805** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 51,813 pounds, or **3,642** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS COPPER.

No. 26.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
5,000	0.012		18,000	0.246	0.202
5,500	0.015		18,500	0.264	
6,000	0.017	0.000	19,000	0.281	
6,500	0.019		19,500	0.305	
7,000	0.020		20,000	0.322	0.269
7,500	0.021		20,500	0.336	
8,000	0.022	0.002	21,000	0.369	
8,500	0.025		21,500	0.397	
9,000	0.030		22,000	0.420	0.371
9,500	0.033		22,500	0.442	
10,000	0.041	0.018	23,000	0.460	
10,500	0.046		23,500	0.496	
11,000	0.052		24,000	0.525	0.469
11,500	0.062		24,500	0.545	
12,000	0.078	0.047	25,000	0.584	
12,500	0.088		25,500	0.612	
13,000	0.097		26,000	0.643	0.582
13,500	0.111		26,500	0.676	
14,000	0.125	0.091	27,000	0.710	
14,500	0.133		27,500	0.758	
15,000	0.152		28,000	0.797	0.732
15,500	0.170		28,500	0.830	
16,000	0.182	0.140	29,000	0.869	
16,500	0.203		29,500	0.897	
17,000	0.215		30,000	0.938	0.870
17,500	0.232		39,896	Rupture.	2.470

CONCLUSIONS RESPECTING PHOSPHOROUS COPPER.

From these trials it results—

1st. That the elastic resistance, the absolute resistance, and the hardness of copper increase, at least to a certain extent, in a very considerable ratio, by reason of the proportion of combined phosphorus.

2d. That on account of the volatilization of phosphorus, it is impossible to obtain a compact casting of phosphorous copper having a proportion of phosphorus greater than 2 per cent.

3d. That with the maximum content of 2 per cent. of phosphorus, the copper is much too soft to use in the manufacture of cannon; and, finally,

4th. That the anomalies resulting from the volatilization of phosphorus contained in rich phosphorides will be, in every case, an obstacle to the use of this combination.

PHOSPHOROUS BRONZE.

MIXTURE OF COPPER, TIN, AND PHOSPHORUS.

The remarkable result obtained by the addition of phosphorus to copper, an addition by which the elastic resistance is increased in the proportion of 220 to 100, and the absolute resistance in the proportion of 575 to 100, led us to make a series of trials designed to discover the effect produced on the characteristics of ordinary bronze by the addition of phosphorus.

MELTING THE METALS.

First trial.—In fusing and cooling six kilogrammes of phosphoric bronze in the manner described in the introduction to this essay, we obtained the following results:

	Tin.	Phosphorus.
The bronze used contained.....	9.925	1.133
Part solidified in crucible.....	9.605	0.995
The metal under the solidified crust.....	10.320	1.105
The metal run off during the cooling process.....	11.260	1.190

Second trial.—In operating in the same manner with 9.20 kilogrammes of phosphoric bronze, the following results were obtained :

	Tin.	Phosphorus.
The bronze used contained.....	9.97	1.170
Part solidified in the crucible.....	9.17	0.742
The metal below the solidified crust.....	10.38	1.279
Metal run off during the cooling process.....	1.738	0.946

These trials proved that the addition of phosphorus is without effect on the melting, and that the separation of the mixture in cooling in different mixtures of unequal proportions is neither more nor less easy than with ordinary bronze.

FUSING POINT OF PHOSPHORIC BRONZE.

We determined the point of fusion of several kinds of phosphoric bronzes in the manner described above for ordinary bronze.

With a bronze containing 9.97 of tin and 1.17 of phosphorus, we obtained the following results :

Original temperature of water.....	24° 50 C.
Weight of water.....	5 kilos.
Temperature of water after the introduction of the metal.....	37° 5 C.
Weight of metal.....	0.585 kilo.
Specific heat assumed.....	0.09219

From which we obtain, by the formula given above, (for the temperature of solidification or of fusion,) 1242° C.

A second trial with a bronze containing 10.15 per cent. of tin and 1.08 per cent. of phosphorus gave results as follow :

Original temperature of water.....	24° C.
Weight of water.....	5 kilos.
Temperature of water after the introduction of the metal.....	41° 5 C.
Weight of metal.....	0.697 kilo.
Corresponding to a temperature of.....	1248° C.

The fusing point of ordinary bronze having been fixed at 1239° C., it is seen that that of phosphoric bronze differs from it but very little, unless there is a very great difference between the specific heat of phosphorus at a high temperature and that which we have adopted from Regnault for a temperature between 0 and 100°. Even in this case it is inadmissible that this

difference may have an influence of any importance on the known temperature, in view of the very minute proportion of phosphorus contained in the mixture.

In the mean time we observe how an expert, accustomed to casting ordinary bronze, is strangely deceived, as we ourselves were deceived, in judging of the temperature of the metal from the appearance of the bath.

In reality, ordinary bronze containing an oxide in process of dissolving neither assumes nor retains a brilliant surface, except at a high temperature, beyond 2000°C . At this temperature, the bath being excessively fluid, the oxides separate and float about in coming together on the edges, while at an inferior temperature, about 1800°C ., the suboxide of tin dissolves in the metal, giving to the surface a dull appearance, the less brilliant as the temperature of the bath is lower.

The presence of phosphorus in the bath, even in a very small quantity, rendering impossible the total dissolution of the oxide, and carrying off all the oxygen, whether in the state of phosphoric acid or in that of phosphate of copper, forming a very fusible dross, is the cause of the bath preserving its mirror-like surface up to the moment when the metal becomes like paste.

MODIFICATION OF COMPOSITION BY SUCCESSIVE FUSIONS.

If phosphorous bronzes, sufficiently divided, are re-cast uncovered in the air, the yield of phosphorus is found reduced in the proportion of three to four-tenths per cent. If, on the contrary, this fusion is made under a layer of charcoal, the diminution is only about one-tenth per cent.

We have seen that in fusing ordinary bronze the yield of tin is diminished with a certain rapidity; on the contrary, with phosphorous bronze the yield of tin remains constant, or is increased in a small proportion, even, as shown in the following table; and this is explained by the elimination of phosphorus in the state of phosphate of copper.

The following table, a résumé of a certain number of analyses, shows beyond question this constancy in the yield of tin :

COMPOSITION BEFORE FUSION.		COMPOSITION AFTER FUSION.		DIFFERENCE IN THE COMPOSITION.		REMARKS.
<i>Tin.</i>	<i>Phosphorus.</i>	<i>Tin.</i>	<i>Phosphorus.</i>	<i>Tin.</i>	<i>Phosphorus.</i>	
9.97	0.11	9.94	0.02	— 0.03	— 0.09	Recast under charcoal.
9.02	1.00	9.04	0.90	+ 0.02	— 0.10	Recast under charcoal.
9.92	1.13	9.85	1.03	— 0.07	— 0.10	Recast under charcoal.
8.58	1.74	8.60	1.61	+ 0.02	— 0.13	Recast under charcoal.
10.60	2.57	10.66	2.34	+ 0.06	— 0.23	Recast under charcoal.
10.32	0.58	10.41	0.26	+ 0.09	— 0.32	Recast in open air.
10.02	1.07	10.09	0.61	+ 0.07	— 0.46	Recast in open air.
9.97	1.17	9.84	0.76	— 0.13	— 0.41	Recast in open air.

But this remarkable retention of composition ought, without doubt, to be attributed, in some measure, to another cause, the existence of an alloy, or rather constant combination, of tin and phosphorus.

If we heat, at a moderate temperature, thin sheets of tin in the vapor of phosphorus, the tin is transformed into a friable mass of a gray color, containing about twenty-one and one-half per cent. of phosphorus; perhaps a phosphoride of tin, with two equivalents of tin and one of phosphorus. This phosphoride is produced more easily by heating phosphorus and tin in a closed tube.

If we take this phosphoride, or any other rich in phosphorus, and heat it with air or burn it over the flame of an alcohol-lamp, a certain quantity of phosphorus is thrown off, leaving a constant phosphoride containing one equivalent of phosphorus and nine of tin.

The easiest way of getting it is to place phosphorus at the bottom of a crucible, and ram over it a spongy tin obtained by the precipitation of chloride of tin by zinc. Putting in a little less tin than is necessary to obtain the indicated combination, about ninety-four parts of tin to six of phosphorus, and heating at a sufficiently low temperature to prevent the total escape of phosphorus, the whole of the metal is transformed into a phosphoride of nine equivalents of tin and one of phosphorus.

If this operation is performed with the addition of a much greater proportion of tin, it forms a genuine alloy of phosphoride, as indicated above, with metallic tin. Indeed, if the crucible is allowed to cool, the alloy crystallizes on account of this cooling; but the constant phosphoride being less fusible than the tin, (it melts at about 400° C.,) crystallizes in the first place, and, if the crucible is reversed at the proper moment, the surplus tin runs off in the metallic state, all the phosphorus remaining in combination with the crystallized part.

A series of analyses of phosphoride obtained by one or the other of the processes aforesaid has given, as the yield in phosphorus, 5.75 per cent., 5.53 per cent., 5.61 per cent., 5.49 per cent., and 5.51 per cent., the mean of the five trials being 5.58 per cent. Now, by computation, a phosphoride of tin, with one equivalent of phosphorus and nine of tin, ought to contain 5.605 per cent. of phosphorus. It is seen that these results agree perfectly.

SPECIFIC GRAVITY OF PHOSPHOROUS BRONZE.

A series of trials to determine the specific gravity of phosphorous bronze of various mixtures, compiled in the following table, has led to the rather remarkable observation that with a low yield of phosphorus, below one per cent., the specific gravity found by experiment is higher than that determined by computation, while the contrary is the case with yields of phosphorus above one per cent.

In the computations we have assumed the specific gravity of copper as 8.92, of tin 7.29, and of phosphorus 2.03.

YIELD OF BRONZE.		PROPORTION OF PHOSPHORUS TO TIN.	SPECIFIC GRAVITY.		DIFFERENCE.	
Phosphorus.	Tin.		Actual.	Computed.	Plus.	Minus.
0.02	10	1 P. to 500 Sn.	8.816	8.756	0.060	
0.25	10	1 P. to 40 Sn.	8.797	8.740	0.057	
0.60	10	1 P. to 16.6 Sn.	8.798	8.715	0.083	
0.75	10	1 P. to 13.3 Sn.	8.832	8.703	0.130	
0.90	10	1 P. to 11.10 Sn.	8.716	8.695	0.021	
1.50	10	1 P. to 6.6 Sn.	8.592	8.653		0.061
2.00	10	1 P. to 5 Sn.	8.555	8.619		0.064
2.50	10	1 P. to 4 Sn.	8.497	8.583		0.086
3.00	10	1 P. to 3.3 Sn.	8.463	8.550		0.087
1.60	8½	1 P. to 5.4 Sn.	8.590	8.659		0.069
1.50	5	1 P. to 3.3 Sn.	8.675	8.735		0.060
1.80	6	1 P. to 3.2 Sn.	8.612	8.698		0.086
2.50	5	1 P. to 2 Sn.	8.546	8.673		0.127

PHOSPHOROUS BRONZE

CONTAINING 0.02 PER CENT. OF PHOSPHORUS AND 10 PER CENT. OF
TIN.

No. 27.

THE ANALYSIS OF THE BAR GAVE :

0.02 phosphorus.

9.94 tin.

89.56 copper.

Total, 99.52

Temperature of the water.....	23 $\frac{1}{2}$ ° C.
Weight of the water.....	5 kilos.
Temperature of the water after introduction of metal.....	42 $\frac{1}{2}$ ° C.
Weight of metal.....	0.714 kilo.
Specific heat assumed.....	0.09126

The bar was cast at 1514° C., in a cold ingot-mold.

Specific gravity of the turned bar.....	8.707
Specific gravity of a specimen from top of bar.....	8.816
Specific gravity of a specimen from bottom of bar.....	8.712

The bar contained, therefore—

1.24 PER CENT. OF CAVITIES AND 98.76 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.816.

The trial under the hydraulic press gave the following :

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.09 inches.
Section of bar at point of rupture.....	0.933 square inch
Contraction of section.....	6.7 per cent.
Final permanent elongation.....	6.8 per cent.

We obtained, also, for an alloy of phosphorous bronze of 10 per cent.
tin with a trace of phosphorus, cast at 1514° C., in a cold ingot-mold :An *elastic* resistance of 19,300 pounds per square inch, or 1,357 kilo-
grammes per square centimetre.An *absolute* resistance at the original section of 33,916 pounds, or 2,384
kilogrammes per square centimetre.An *absolute* resistance, at the point of rupture, of 36,390 pounds, or 2,558
kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 27.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.026		20,500	0.067	
10,500	0.027		21,000	0.074	
11,000	0.028		21,500	0.078	
11,500	0.029		22,000	0.083	0.038
12,000	0.030		22,500	0.092	
12,500	0.031		23,000	0.098	
13,000	0.032		23,500	0.101	
13,500	0.033		24,000	0.115	0.074
14,000	0.035	0.000	24,500	0.132	
14,500	0.036		25,000	0.152	
15,000	0.037		25,500	0.171	
15,500	0.038		26,000	0.192	0.160
16,000	0.040	0.003	26,500	0.212	
16,500	0.042		27,000	0.236	
17,000	0.044		27,500	0.260	
17,500	0.048		28,000	0.285	0.262
18,000	0.050	0.007	28,500	0.310	
18,500	0.053		29,000	0.332	
19,000	0.056		29,500	0.360	
19,500	0.059		30,000	0.387	0.370
20,000	0.063	0.015	33,916	Rupture.	0.680

PHOSPHOROUS BRONZE

CONTAINING **0.25** PER CENT. OF PHOSPHORUS AND **10** PER CENT. OF TIN.

No. 28.

THE ANALYSIS OF THE BAR GAVE:

0.26 phosphorus.
10.41 tin.
89.20 copper.

Total, **99.87**

Temperature of the water.....	20° 75 C.
Weight of the water.....	5 kilos.
Temperature of the water after introduction of the metal.....	46° C.
Weight of metal.....	0.858 kilo
Specified heat assumed.....	0.09173

COMPUTED TEMPERATURE OF THE CASTING, **1650° C.**

Specific gravity of the turned bar.....	8.539
Specific gravity of specimen from the top.....	8.797
Specific gravity of specimen from bottom.....	8.842

The bar contained therefore—

3.43 PER CENT. OF CAVITIES AND **96.57** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.842**.

The trial under the hydraulic press gave:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.110 inches.
Section of bar at point of rupture.....	0.967 square inch.
Contraction of section.....	3.3 per cent.
Final permanent elongation.....	1.9 per cent.

We obtained, also, for a phosphorous bronze, with 10 per cent. of tin and 0.26 per cent. of phosphorus, cast at 1650° C., in a cold ingot-mold:

An *elastic* resistance of 17,600 pounds per square inch, or **1,237** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 26,552 pounds, or **1,866** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 27,458 pounds, or **1,930** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 28.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018	
10,500	0.019	
11,000	0.020	
11,500	0.021	
12,000	0.022	
12,500	0.023	
13,000	0.025	
13,500	0.027	
14,000	0.028	0.004
14,500	0.030	
15,000	0.032	
15,500	0.034	
16,000	0.036	0.005
16,500	0.038	
17,000	0.040	
17,500	0.042	
18,000	0.046	0.009
18,500	0.050	
19,000	0.054	
19,500	0.059	
20,000	0.062	0.020
20,500	0.065	
21,000	0.071	
21,500	0.076	
22,000	0.087	0.042
22,500	0.097	
23,000	0.103	
23,500	0.110	
24,000	0.121	0.080
24,500	0.140	
25,000	0.148	
25,500	0.158	
26,000	0.177	0.128
26,500	0.198	
26,552	Rupture.	0.190

PHOSPHOROUS BRONZE

CONTAINING 10 PER CENT. OF TIN AND 0.60 PER CENT. OF PHOSPHORUS.

No. 29.

THE ANALYSIS OF THE BAR GAVE:

0.618 phosphorus.
 10.09 tin.
 89.02 copper.

Total, 99.728

Temperature of the water.....	20½° C.
Weight of the water.....	5 kilos.
Temperature of the water after the introduction of the metal..	37½° C.
Weight of metal.....	0.585 kilo.
Specific heat assumed.....	0.09219

COMPUTED TEMPERATURE OF THE CASTING, 1613° C.

Specific gravity of the turned bar.....	8.152
Specific gravity of specimen from top of bar.....	8.609
Specific gravity of specimen from bottom of bar.....	8.626

The bar contained, therefore—

5.50 PER CENT. OF CAVITIES AND 94.50 PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF 8.626.

The trial under the hydraulic press gave the following:

Original diameter of bar.....	1.128 inches.
Original section of bar.....	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.113 inches.
Section of bar at point of rupture.....	0.972 square inch.
Contraction of section.....	2.8 per cent.
Final permanent elongation.....	1.5 per cent.

We obtained, also, for a phosphorous bronze, with 10 per cent. of tin
 and 0.60 per cent. of phosphorus, cast at 1613° C., in a cold ingot-mold:

An *elastic* resistance of 22,700 pounds per square inch, or 1,596 kilo-
 grammes per square centimetre.

An *absolute* resistance of the original section of 36,244 pounds, or 2,567
 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 37,289 pounds, or 2,622
 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 29.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.017		22,000	0.049	0.009
10,500	0.018		22,500	0.051	
11,000	0.019		23,000	0.055	
11,500	0.020		23,500	0.058	
12,000	0.021		24,000	0.061	0.019
12,500	0.022		24,500	0.065	
13,000	0.023		25,000	0.068	
13,500	0.023		25,500	0.070	
14,000	0.024	0.001	26,000	0.073	0.029
14,500	0.025		26,500	0.078	
15,000	0.027		27,000	0.082	
15,500	0.029		27,500	0.086	
16,000	0.029	0.002	28,000	0.090	0.040
16,500	0.030		28,500	0.094	
17,000	0.031		29,000	0.099	
17,500	0.032		29,500	0.107	
18,000	0.033	0.003	30,000	0.113	0.059
18,500	0.035		30,500	0.122	
19,000	0.037		31,000	0.141	
19,500	0.039		32,000	0.162	
20,000	0.040	0.005	33,000	0.178	
20,500	0.042		34,000	0.192	
21,000	0.044		35,000	0.213	
21,500	0.046		36,244	Rupture.	0.150

PHOSPHOROUS BRONZE

CONTAINING 75 PER CENT. OF PHOSPHORUS AND 10 PER CENT. OF TIN.

No. 30.

THE ANALYSIS OF THE BAR GAVE :

0.742 phosphorus.
 9.89 tin.
 89.00 copper.

Total, 99.632

Temperature of the water..... $16\frac{1}{2}^{\circ}$ C.
 Weight of the water..... 5 kilos.
 Temperature of the water after the introduction of the metal.. 41° C.
 Weight of metal..... 0.945 kilo.
 Specific heat assumed..... 0.09219

COMPUTED TEMPERATURE OF THE CASTING, 1435° C.

Specific gravity of the turned bar..... 8.673
 Specific gravity of sample from top of bar..... 8.751
 Specific gravity of sample from bottom of bar..... 8.832

The bar, therefore, contained—

1.80 PER CENT. OF CAVITIES AND 98.20 PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF 8.832.

The test under the hydraulic press gave :

Original diameter of bar..... 1.128 inches.
 Original section of bar..... 1 square inch.
 Original length of bar..... 10 inches.
 Diameter of bar at point of rupture..... 1.12 inches.
 Section of bar at point of rupture..... 0.985 square inch.
 Contraction of section..... 1.5 per cent.
 Final permanent elongation..... 1.5 per cent.

A phosphorous bronze, with 10 per cent. of tin and 0.742 per cent. of phosphorus, cast in a cold ingot-mold at 1435° C., had also :

An *elastic* resistance of 24,700 pounds per square inch, or 1,736 kilogrammes per square centimetre.

An *absolute* resistance at the original section of 40,312 pounds, or 2,834 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 40,926 pounds, or 2,879 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 30.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.019		23,000	0.051	
10,500	0.020		23,500	0.052	
11,000	0.021		24,000	0.053	0.007
11,500	0.022		24,500	0.054	
12,000	0.023		25,000	0.058	
12,500	0.024		25,500	0.060	
13,000	0.025		26,000	0.062	0.012
13,500	0.026		26,500	0.064	
14,000	0.027		27,000	0.067	
14,500	0.028		27,500	0.069	
15,000	0.029		28,000	0.071	0.019
15,500	0.030		28,500	0.073	
16,000	0.032		29,000	0.077	
16,500	0.033		29,500	0.080	
17,000	0.034		30,000	0.083	0.028
17,500	0.036		31,000	0.090	
18,000	0.037		32,000	0.097	
18,500	0.038		33,000	0.103	
19,000	0.039		34,000	0.122	
19,500	0.040		35,000	0.136	
20,000	0.042	0.003	36,000	0.150	
20,500	0.043		37,000	0.160	
21,000	0.045		38,000	0.187	
21,500	0.046		39,000	0.211	
22,000	0.048	0.005	40,000	0.230	
22,500	0.050		40,312	Rupture.	0.150

PHOSPHOROUS BRONZE

CONTAINING **75** PER CENT. OF PHOSPHORUS AND **10** PER CENT. OF TIN, THE CASTING COOLED SLOWLY.

No. 31.

The same metal used in the preceding proof, and which had been cooled quickly, was cast in a sand mold in order to observe the effect of slow cooling.

1st. One bar at a temperature of **1549° C.:**

Specific gravity of the turned bar was	8.121
Specific gravity of a sample of this bar	8.709

The bar contained, therefore—

6.75 PER CENT. OF CAVITIES AND **93.25** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.709**.

2d. A bar at a temperature of **1430° C.:**

Specific gravity of the turned bar	8.302
Specific gravity of sample from this bar	8.709

The bar contained, therefore—

4.67 PER CENT. OF CAVITIES AND **95.33** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.709**.

3d. A bar at a temperature of **1397° C.:**

Specific gravity of the turned bar	8.318
Specific gravity of a sample from this bar	8.709

The bar, therefore, contained—

4.50 PER CENT. OF CAVITIES AND **95.50** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.709**.

It is shown by these trials that the pieces cooled slowly in the molds became proportionally less dense as the temperature of the casting was made higher.

Only the third bar, cast at a temperature of 1397° C., was subjected to the proof for resistance, as it showed less cavities, and should, therefore, give the most favorable result.

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of bar at point of rupture.....	1.120 inches.
Section of bar at point of rupture.....	0.985 square inch.
Contraction of the section.....	1.5 per cent.
Final permanent elongation.....	1.8 per cent.

We also obtained, with a phosphorous bronze containing 10 per cent. of tin and 75 per cent. of phosphorus, cast at a temperature of 1397°C. , in sand:

An *elastic* resistance of 20,100 pounds per square inch, or **1,413** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 28,130 pounds, or **1,977** kilogrammes per square centimetre.

An *absolute* resistance, with the section of rupture, of 28,553 pounds, or **2,007** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 31.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018		19,500	0.042	
10,500	0.019		20,000	0.043	0.010
11,000	0.020		20,500	0.046	
11,500	0.022		21,000	0.052	
12,000	0.023	0.001	21,500	0.056	
12,500	0.024		22,000	0.059	0.019
13,000	0.025		22,500	0.064	
13,500	0.026		23,000	0.074	
14,000	0.027	0.002	23,500	0.082	
14,500	0.028		24,000	0.093	0.048
15,000	0.030		24,500	0.102	
15,500	0.032		25,000	0.112	
16,000	0.033	0.004	25,500	0.122	
16,500	0.035		26,000	0.133	0.102
17,000	0.036		26,500	0.150	
17,500	0.037		27,000	0.164	
18,000	0.038	0.006	27,500	0.178	
18,500	0.040		28,000	0.190	
19,000	0.041		28,130	Rupture.	0.180

PHOSPHOROUS BRONZE

CONTAINING 0.9 PER CENT. OF PHOSPHORUS AND 9 PER CENT. OF TIN.

No. 32.

THE ANALYSIS OF THE BAR GAVE:

0.904 phosphorus.
 9.06 tin.
 89.16 copper.

Total, 99.124

Temperature of the water 21° C.
 Weight of the water 5 kilos.
 Temperature of the water after the introduction of the metal... 48° C.
 Weight of metal 1.035 kilos.
 Specific heat assumed 0.9258.

COMPUTED TEMPERATURE OF THE CASTING, 1457° C.

Specific gravity of the turned bar was 8.557
 Specific gravity of sample from top of bar 8.708
 Specific gravity of sample from bottom of bar 8.716

The bar, therefore, contained—

1.81 PER CENT. OF CAVITIES AND 98.19 PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF 8.716.

The test under the hydraulic press gave as follows:

Original diameter of the bar 1.128 inches.
 Original section of the bar 1 square inch.
 Original length of the bar 10 inches.
 Diameter of the bar at point of rupture 1.110 inches.
 Section of the bar at point of rupture 0.967 square inch.
 Contraction of the section 3.3 per cent.
 Final permanent elongation 2.0 per cent.

We obtained, also, with a phosphorous bronze, having 9 per cent. of tin and 0.9 per cent. of phosphorus, cast at 1457° C., in a cold ingot-mold: An *elastic* resistance of 19,800 pounds per square inch, or 1,392 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 31,956 pounds, or 2,246 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 33,045 pounds, or 2,323 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 32.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018		21,000	0.063	
10,500	0.019		21,500	0.067	
11,000	0.021		22,000	0.071	0.030
11,500	0.022		22,500	0.078	
12,000	0.023		23,000	0.083	
12,500	0.024		23,500	0.089	
13,000	0.025		24,000	0.097	0.050
13,500	0.027		24,500	0.102	
14,000	0.029	0.004	25,000	0.109	
14,500	0.030		25,500	0.113	
15,000	0.032		26,000	0.122	0.071
15,500	0.034		26,500	0.131	
16,000	0.037	0.005	27,000	0.142	
16,500	0.039		27,500	0.153	
17,000	0.041		28,000	0.162	0.104
17,500	0.043		28,500	0.179	
18,000	0.046	0.009	29,000	0.188	
18,500	0.048		29,500	0.196	
19,000	0.050		30,000	0.204	0.150
19,500	0.052		31,000	0.240	
20,000	0.056	0.014	31,956	Rupture.	0.200
20,500	0.060				

PHOSPHOROUS BRONZE

CONTAINING 1.5 PER CENT. OF PHOSPHORUS AND 5 PER CENT. OF TIN.

No. 33.

THE ANALYSIS OF THE BAR GAVE:

1.56 phosphorus.

5.10 tin.

93.06 copper.

Total, 99.72

Temperature of the water	24° C.
Weight of the water	5 kilos.
Temperature of the water after the introduction of metal	86° C.
Weight of metal	2.360 kilos.
Specific heat assumed	0.09471.

COMPUTED TEMPERATURE OF THE CASTING, 1472° C.

Specific gravity of the turned bar	8.524
Specific gravity of sample from top of bar	8.675
Specific gravity of sample from bottom of bar	8.672

The bar, therefore, contained—

1.74 PER CENT. OF CAVITIES AND 98.26 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.675.

The test under the hydraulic press gave:

Original diameter of the bar	1.128 inches.
Original section of the bar	1 square inch.
Original length of the bar	10 inches.
Diameter of bar at point of rupture	1.090 inches.
Section of bar at point of rupture	0.933 square inch.
Contraction of section	6.7 per cent.
Final permanent elongation	6.2 per cent.

We also obtained, with a phosphorous bronze containing 5 per cent. of tin and 1.5 per cent. of phosphorus, cast at 1472° C., in a cold ingot-mold:

An *elastic* resistance of 20,800 pounds per square inch, or 1,462 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 37,504 pounds, or 2,636 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 40,197 pounds, or 2,826 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 33.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.021		22,500	0.056	
10,500	0.022		23,000	0.058	
11,000	0.023		23,500	0.060	
11,500	0.024		24,000	0.062	0.024
12,000	0.025		24,500	0.064	
12,500	0.026		25,000	0.067	
13,000	0.027		25,500	0.071	
13,500	0.029		26,000	0.076	0.034
14,000	0.030	0.002	26,500	0.082	
14,500	0.031		27,000	0.088	
15,000	0.033		27,500	0.097	
15,500	0.034		28,000	0.106	0.056
16,000	0.035	0.004	28,500	0.119	
16,500	0.036		29,000	0.131	
17,000	0.038		29,500	0.150	
17,500	0.039		30,000	0.168	0.117
18,000	0.040	0.006	31,000	0.217	
18,500	0.042		32,000	0.277	
19,000	0.043		33,000	0.340	
19,500	0.045		34,000	0.416	
20,000	0.046	0.008	35,000	0.490	
20,500	0.047		36,000	0.564	
21,000	0.050		37,000	0.610	
21,500	0.052		37,504	Rupture.	0.620
22,000	0.054	0.016			

PHOSPHOROUS BRONZE

CONTAINING 1.6 PER CENT. OF PHOSPHORUS AND 8.5 PER CENT. OF TIN.

No 34.

THE ANALYSIS OF THE BAR GAVE :

1.61 phosphorus.
 8.60 tin.
 89.42 copper.

Total, 99.63

Temperature of the water	21° C.
Weight of the water	5 kilos.
Temperature of the water after the introduction of the metal...	53½° C.
Weight of metal	1.220 kilos.
Specific heat assumed	0.09324.

COMPUTED TEMPERATURE OF THE CASTING, 1481° C.

Specific gravity of the turned bar	8.476
Specific gravity of sample from top of the bar	8.504
Specific gravity of sample from bottom of the bar	8.583

The bar, therefore, contained—

1.25 PER CENT. OF CAVITIES AND 98.75 PER CENT. OF METAL HAVING A
 SPECIFIC GRAVITY OF 8.583.

The trial under the hydraulic press gave :

Original diameter of the bar	1.128 inches.
Original section of the bar	1 square inch.
Original length of the bar	10 inches.
Diameter of bar at point of rupture	1.120 inches.
Section of bar at point of rupture	0.985 square inch.
Contraction of the section	1.5 per cent.
Final permanent elongation	1.6 per cent.

We also obtained, for a phosphorous bronze, containing 8.5 per cent. of tin and 1.6 of phosphorus, cast at 1481° C., in a cold ingot-mold :

An *elastic* resistance of 24,300 pounds per square inch, or 1,708 kilogrammes per square centimetre.

An *absolute* resistance with the original section of 41,228 pounds, or 2,900 kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 41,950 pounds, or 2,943 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 34.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.017		23,000	0.049	
10,500	0.018		23,500	0.051	
11,000	0.019		24,000	0.053	0.010
11,500	0.020		24,500	0.058	
12,000	0.021		25,000	0.060	
12,500	0.021		25,500	0.062	
13,000	0.022		26,000	0.063	0.020
13,500	0.023		26,500	0.065	
14,000	0.024	0.001	27,000	0.070	
14,500	0.026		27,500	0.074	
15,000	0.027		28,000	0.079	0.029
15,500	0.029		28,500	0.081	
16,000	0.030	0.002	29,000	0.084	
16,500	0.031		29,500	0.088	
17,000	0.032		30,000	0.091	0.038
17,500	0.033		31,000	0.098	
18,000	0.034	0.003	32,000	0.107	
18,500	0.036		33,000	0.119	
19,000	0.037		34,000	0.129	
19,500	0.038		35,000	0.136	
20,000	0.040	0.004	36,000	0.158	
20,500	0.041		37,000	0.162	
21,000	0.043		38,000	0.180	
21,500	0.044		39,000	0.196	
22,000	0.046	0.007	40,000	0.211	
22,500	0.047		41,228	Rupture.	0.160

PHOSPHOROUS BRONZE

CONTAINING 8.5 PER CENT. OF TIN AND 1.6 PER CENT. OF PHOSPHORUS.

No. 35.

THE ANALYSIS OF THE BAR GAVE :

1.58 phosphorus.

8.52 tin.

89.40 copper.

Total, 99.50

Temperature of the water	24° C.
Weight of the water	5 kilos.
Temperature of the water after the introduction of the metal...	62° C.
Weight of the metal	1.540 kilos.
Specific heat assumed	0.09258.

COMPUTED TEMPERATURE OF THE CASTING, 1398° C.

Specific gravity of the turned bar	8.487
Specific gravity of sample from top of bar	8.534
Specific gravity of sample from bottom of bar	8.590

The bar, therefore, contained—

1.20 PER CENT. OF CAVITIES AND 98.80 PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF 8.590.

The trial under the hydraulic press gave :

Original diameter of the bar	1.128 inches.
Original section of the bar	1 square inch.
Original length of the bar	10 inches.
Diameter of the bar at the point of rupture	1.120 inches.
Section of bar at point of rupture	0.985 square inch.
Contraction of the section	1.5 per cent.
Final permanent elongation	1.6 per cent.

With a phosphorous bronze, having 8.5 per cent. of tin and 1.6 per cent. of phosphorus, cast at 1398° C., in a cold ingot-mold, we obtained :

An *elastic* resistance of 24,700 pounds per square inch, or **1,736** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 46,108 pounds, or **3,241** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 46,810 pounds, or **3,290** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 35.

TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.017		23,000	0.047	
10,500	0.018		23,500	0.048	
11,000	0.019		24,000	0.050	0.009
11,500	0.020		24,500	0.051	
12,000	0.021		25,000	0.054	
12,500	0.022		25,500	0.059	
13,000	0.023		26,000	0.060	0.019
13,500	0.024		26,500	0.062	
14,000	0.025	0.001	27,000	0.063	
14,500	0.026		27,500	0.065	
15,000	0.028		28,000	0.068	0.028
15,500	0.029		28,500	0.070	
16,000	0.030	0.002	29,000	0.075	
16,500	0.031		29,500	0.078	
17,000	0.032		30,000	0.084	0.030
17,500	0.033		31,000	0.091	
18,000	0.034	0.003	32,000	0.098	
18,500	0.035		33,000	0.106	
19,000	0.036		34,000	0.115	
19,500	0.037		35,000	0.125	
20,000	0.038	0.004	36,000	0.136	
20,500	0.040		37,000	0.148	
21,000	0.041		38,000	0.159	
21,500	0.042		39,000	0.175	
22,000	0.044	0.006	40,000	0.193	
22,500	0.046		46,108	Rupture.	0.160

PHOSPHOROUS BRONZE

CONTAINING 1.6 PER CENT. OF PHOSPHORUS, 8.5 PER CENT. OF TIN,
AND COOLED SLOWLY.

No. 36.

The same bronze, of which we cast the two preceding bars, was cast in sand in order to observe the influence upon the qualities of the bronze, when cast at a high or low temperature, and cooled slowly.

We cast, at different temperatures, four bars:

1st. One bar at **1589° C.:**

The specific gravity of the turned bar was 7.679

The specific gravity of a specimen of this bar 8.605

The bar, therefore, contained—

10.76 PER CENT. OF CAVITIES AND **89.24** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.605**.

2d. A bar at **1484° C.:**

Specific gravity of the turned bar was 7.979

Specific gravity of a specimen from this bar 8.605

The bar, therefore, contained—

7.27 PER CENT. OF CAVITIES AND **92.73** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.605**.

3d. A bar at **1451° C.:**

Specific gravity of the turned bar was 8.056

Specific gravity of specimen from this bar 8.605

The bar, therefore, contained—

6.38 PER CENT. OF CAVITIES AND **93.62** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.605**.

4th. A bar at **1380° C.:**

Specific gravity of the turned bar was 8.305

Specific gravity of a sample of this bar 8.605

The bar, therefore, contained—

3.36 PER CENT. OF CAVITIES AND **96.64** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.605**.

In view of the great number of cavities in the bars, cast at high temperatures and cooled slowly, we submitted only the fourth bar, cast at 1380°C ., to the proof of resistance.

THE ANALYSIS OF THIS BAR GAVE:

1.667 phosphorus.
8.449 tin.
89.360 copper.

Total, **99.476**

The trial under the hydraulic press gave:

Original diameter of the bar.....	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar.....	10 inches.
Diameter of the bar at the point of rupture.....	1.120 inches.
Section of the bar at the point of rupture.....	0.985 square inch.
Contraction of the section.....	1.5 per cent.
Final permanent elongation.....	1.5 per cent.

With a phosphorous bronze, having 8.5 per cent. of tin and 1.6 per cent. of phosphorus, cast at 1380°C ., in sand, that is to say, cooled slowly, we obtained:

An *elastic* resistance of 20,600 pounds per square inch, or **1,448** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 28,858 pounds, or **2,028** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 29,297 pounds, or **2,059** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 36.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.020		20,000	0.046	0.007
10,500	0.021		20,500	0.049	
11,000	0.023		21,000	0.054	
11,500	0.024		21,500	0.059	
12,000	0.025	0.001	22,000	0.064	0.017
12,500	0.026		22,500	0.068	
13,000	0.027		23,000	0.073	
13,500	0.027		23,500	0.080	
14,000	0.028	0.002	24,000	0.087	0.036
14,500	0.029		24,500	0.097	
15,000	0.030		25,000	0.103	
15,500	0.031		25,500	0.114	
16,000	0.033	0.003	26,000	0.124	0.065
16,500	0.034		26,500	0.134	
17,000	0.034		27,000	0.143	
17,500	0.036		27,500	0.154	
18,000	0.037	0.005	28,000	0.165	
18,500	0.039		28,500	0.176	
19,000	0.041		28,858	Rupture.	0.150
19,500	0.043				

PHOSPHOROUS BRONZE

CONTAINING **1.8** PER CENT. OF PHOSPHORUS AND **6** PER CENT. OF TIN.

No. 37.

THE ANALYSIS OF THE BAR GAVE :

1.818 phosphorus.

6.10 tin.

92.00 copper.

Total, **99.918**

Temperature of the water	16° 50 C.
Weight of the water	5 kilos.
Temperature of water after the introduction of the metal	35° 50 C.
Weight of the metal	0.735 kilo.
Assumed specific heat	0.09470.

COMPUTED TEMPERATURE OF THE CASTING, **1400° C.**

The specific gravity of the turned bar..... 8.517

The specific gravity of sample from top of bar..... 8.612

The specific gravity of sample from bottom of bar..... 8.600

The bar, therefore, contained—

1.11 PER CENT. OF CAVITIES AND **98.89** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.612**.

The test under the hydraulic press gave :

Original diameter of the bar.....	1.128 inches.
Original section of the bar	1 square inch.
Original length of the bar	10 inches.
Diameter of bar at point of rupture.....	1.07 inches.
Section of bar at point of rupture.....	0.899 square inch.
Contraction of the section.....	10.1 per cent.
Final permanent elongation.....	10.7 per cent.

With a phosphorous bronze, containing 6 per cent. of tin and 1.8 per cent. of phosphorus, cast at 1400° C., in a cold ingot-mold, we obtained :

An *elastic* resistance of 21,600 pounds per square inch, or **1,518** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 51,644 pounds, or **3,630** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 57,457 pounds, or **4,039** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 37.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.020		25,500	0.085	
10,500	0.021		26,000	0.090	0.040
11,000	0.022		26,500	0.095	
11,500	0.023		27,000	0.099	
12,000	0.024		27,500	0.103	
12,500	0.025		28,000	0.108	0.053
13,000	0.027		28,500	0.112	
13,500	0.028		29,000	0.120	
14,000	0.030		29,500	0.126	
14,500	0.031		30,000	0.133	0.077
15,000	0.032		31,000	0.142	
15,500	0.034		32,000	0.166	
16,000	0.036		33,000	0.177	
16,500	0.037		34,000	0.189	
17,000	0.039		35,000	0.208	
17,500	0.041		36,000	0.233	
18,000	0.043		37,000	0.252	
18,500	0.045		38,000	0.278	
19,000	0.047		39,000	0.306	
19,500	0.048		40,000	0.355	
20,000	0.050	0.010	41,000	0.396	
20,500	0.052		42,000	0.442	
21,000	0.053		43,000	0.485	
21,500	0.055		44,000	0.550	
22,000	0.062	0.015	45,000	0.616	
22,500	0.066		46,000	0.684	
23,000	0.069		47,000	0.753	
23,500	0.071		48,000	0.848	
24,000	0.073	0.019	49,000	0.937	
24,500	0.077		50,000	1.000	
25,000	0.081		51,644	Rupture.	1.070

PHOSPHOROUS BRONZE

CONTAINING **2.33** PER CENT. OF PHOSPHORUS AND **10.6** PER CENT. OF TIN.

No. 38.

THE ANALYSIS OF THE BAR GAVE :

2.34 phosphorus.**10.66** tin.**86.21** copper.Total, **99.21**

Temperature of the water.....	22° C.
Weight of the water.....	5 kilos.
Temperature of the water after the introduction of the metal..	41° 25 C.
Weight of the metal.....	0.695 kilo.
Assumed specific heat	0.09313

COMPUTED TEMPERATURE OF THE CASTING, **1511° C.**

The specific gravity of the turned bar.....	7.792
The specific gravity of a sample from top of bar.....	8.469
The specific gravity of a sample from bottom of bar.....	8.316

The bar, therefore, contained—

8 PER CENT. OF CAVITIES AND **92** PER CENT. OF METAL HAVING A SPECIFIC GRAVITY OF **8.469**.

The test under the hydraulic press gave :

Original diameter of the bar	1.128 inches.
Original section of the bar.....	1 square inch.
Original length of the bar	10 inches.
Diameter of bar at the point of rupture.....	1.125 inches.
Section of bar at the point of rupture.....	0.998 square inch.
Contraction of the section.....	2.10 per cent.
Final permanent elongation.....	1 per cent.

With a phosphorous bronze, containing 10.6 per cent. of tin and 2.3 per cent. of phosphorus, cast at 1511° C., in a cold ingot-mold, we obtained:
An *elastic* resistance of 21,900 pounds per square inch, or **1,539** kilogrammes per square centimetre.

An *absolute* resistance with the original section of 25,436 pounds, or **1,788** kilogrammes per square centimetre.

An *absolute* resistance, at the point of rupture, of 25,487 pounds, or **1,791** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 38.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018	
10,500	0.019	
11,000	0.020	
11,500	0.021	
12,000	0.022	
12,500	0.023	
13,000	0.024	
13,500	0.025	
14,000	0.027	0.001
14,500	0.029	
15,000	0.030	
15,500	0.032	
16,000	0.034	0.003
16,500	0.036	
17,000	0.038	
17,500	0.039	
18,000	0.040	0.006
18,500	0.042	
19,000	0.044	
19,500	0.046	
20,000	0.049	0.007
20,500	0.050	
21,000	0.051	
21,500	0.052	
22,000	0.058	0.014
22,500	0.060	
23,000	0.062	
23,500	0.064	
24,000	0.068	0.026
24,500	0.070	
25,000	0.072	
25,436	Rupture.	0.100

PHOSPHOROUS BRONZE

CONTAINING 2.5 PER CENT. OF PHOSPHORUS AND 5 PER CENT. OF TIN.

No. 39.

THE ANALYSIS OF THE BAR GAVE:

2.53 phosphorus.

5.06 tin.

92.12 copper.

Total, 99.71

Temperature of the water	16
Weight of the water	5
Temperature of the water after the introduction of the metal	3
Weight of metal	
Assumed specific heat	

COMPUTED TEMPERATURE OF THE CASTING, 1451° C.

The specific gravity of the turned bar was

The specific gravity of sample from top of bar

The specific gravity of sample from bottom of bar

The bar, therefore, contained—

1.77 PER CENT. OF CAVITIES AND 98.23 PER CENT.

SPECIFIC GRAVITY OF 8.546.

The test under the hydraulic press gave:

Original diameter of the bar

Original section of the bar

Original length of the bar

Diameter of bar at point of rupture

Section of bar at point of rupture

Contraction of the section

Final permanent elongation

With a phosphorous bronze, containing
 cent. of phosphorus, cast at 1451° C., in

An *elastic* resistance of 23,800 pounds
 grammes per square centimetre.

An *absolute* resistance with the original
 kilogrammes per square centimetre.

An *absolute* resistance, at the point of
 kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 39.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.019		25,500	0.065	
10,500	0.020		26,000	0.069	0.025
11,000	0.021		26,500	0.073	
11,500	0.022		27,000	0.077	
12,000	0.023		27,500	0.080	
12,500	0.024		28,000	0.084	0.031
13,000	0.026		28,500	0.088	
13,500	0.027		29,000	0.091	
14,000	0.028		29,500	0.095	
14,500	0.029		30,000	0.099	0.041
15,000	0.030		31,000	0.102	
15,500	0.031		32,000	0.112	
16,000	0.032		33,000	0.121	
16,500	0.033		34,000	0.133	
17,000	0.035		35,000	0.150	
17,500	0.036		36,000	0.160	
18,000	0.037		37,000	0.173	
18,500	0.038		38,000	0.196	
19,000	0.039		39,000	0.215	
19,500	0.041		40,000	0.234	
20,000	0.043	0.005	41,000	0.263	
20,500	0.045		42,000	0.286	
21,000	0.047		43,000	0.314	
21,500	0.048		44,000	0.342	
22,000	0.050	0.008	45,000	0.411	
22,500	0.052		46,000	0.455	
23,000	0.053		47,000	0.510	
23,500	0.054		48,000	0.572	
24,000	0.058	0.013	49,000	0.634	
24,500	0.060		50,000	0.696	
25,000	0.062		52,628	Rupture.	0.780

PHOSPHOROUS BRONZE

CONTAINING **2.5** PER CENT. OF PHOSPHORUS AND **5** PER CENT. OF
TIN, COOLED SLOWLY.

No. 40.

The same bronze from which was cast the preceding bar, and cooled quickly in the mold, was cast in sand in order to observe the influence upon the qualities of this bronze when cooled slowly, and cast at a temperature more or less elevated.

We cast, at different temperatures, three bars—

1st. A bar at **1472° C.:**

The specific gravity of the turned bar 7.803

The specific gravity of a sample of this bar 8.507

The bar, therefore, contained—

8.28 PER CENT. OF CAVITIES AND **91.72** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY **8.507**.

2d. A bar at **1400° C.:**

The specific gravity of this bar was 8.056

The specific gravity of a sample 8.507

The bar, therefore, contained—

5.30 PER CENT. OF CAVITIES AND **94.70** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.507**.

3d. A bar at **1373° C.:**

The specific gravity of this bar was 8.070

The specific gravity of a specimen 8.507

The bar, therefore, contained—

5.13 PER CENT. OF CAVITIES AND **94.87** PER CENT. OF METAL HAVING A
SPECIFIC GRAVITY OF **8.507**.

On account of the great number of cavities in the bars cast at high temperatures and cooled slowly, we only subjected to the proof of resistance the third bar, (No. 3,) cast at 1373° C.

THE ANALYSIS OF THIS BAR GAVE:

2.56 phosphorus.

4.98 tin.

92.10 copper.

Total, **99.64**

The test of the hydraulic press gave :

Original diameter of bar.....	1.128 inches.
Original section of bar	1 square inch.
Original length of bar.....	10 inches.
Diameter of bar at point of rupture.....	1.115 inches.
Section of bar at point of rupture.....	0.978 square inch.
Contraction of the section.....	2.2 per cent.
Final permanent elongation.....	2.4 per cent.

With a phosphorous bronze, containing 5 per cent. of tin and 2.5 per cent. of phosphorus, cast at 1373° C., in sand, and cooled slowly, we obtained :

The *elastic* resistance of 20,700 pounds per square inch, or **1,455** kilogrammes per square centimetre.

The *absolute* resistance with the original section of 31,948 pounds, or **2,246** kilogrammes per square centimetre.

The *absolute* resistance, at the point of rupture, of 32,666 pounds, or **2,296** kilogrammes per square centimetre.

TRIAL OF RESISTANCE.

PHOSPHOROUS BRONZE.

No. 40.

TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.	TENSILE STRAIN.	ELONGATION DURING THE STRAIN.	PERMANENT ELONGATION.
<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>	<i>English pounds.</i>	<i>English inches.</i>	<i>English inches.</i>
10,000	0.018		20,500	0.048	
10,500	0.019		21,000	0.053	
11,000	0.020		21,500	0.058	
11,500	0.021		22,000	0.064	0.017
12,000	0.022		22,500	0.071	
12,500	0.023		23,000	0.079	
13,000	0.024		23,500	0.086	
13,500	0.025		24,000	0.094	0.040
14,000	0.026	0.001	24,500	0.102	
14,500	0.027		25,000	0.110	
15,000	0.029		25,500	0.119	
15,500	0.030		26,000	0.128	0.073
16,000	0.031	0.003	26,500	0.138	
16,500	0.033		27,000	0.148	
17,000	0.035		27,500	0.160	
17,500	0.037		28,000	0.171	
18,000	0.039	0.005	28,500	0.182	
18,500	0.041		29,000	0.196	
19,000	0.042		29,500	0.208	
19,500	0.043		30,000	0.220	
20,000	0.044	0.007	31,948	Rupture.	0.240

CONCLUSIONS FROM THE TRIALS OF PHOSPHOROUS BRONZE.

From a summary of these trials it results :

1st. That the hardness of this bronze is far superior to that of ordinary cannon-bronze; for, in comparing the diminution of section in bars subjected to a breaking strain, we find, as the mean of nine trials with ordinary bronze, a contraction of 4.70 per cent. under a pressure of 23,156 pounds per inch; while, as the mean of fourteen trials with phosphorous bronze, the section was reduced only 3.65 per cent. under a pressure of 36,047 pounds. Moreover, with phosphorous bronze it is easy to obtain the desired degree of hardness, and it is seen from the recorded results that certain samples, with 10 and 8.5 per cent. of tin in them, exhibit a hardness five times as great as ordinary bronze.

One of our trial-bars, containing 10.60 per cent. of tin, and having an *elastic* resistance of 1,540 kilogrammes per centimetre, and an *absolute* resistance of 1,790 kilogrammes, was so hard that it required tools of the best steel to cut it, and those of ordinary steel were flattened upon it.

A mechanic had to work twenty hours to turn this bar to a depth of 12 millimetres in a length of 25 centimetres; and, with all the bars of phosphorous bronze, the turning took at least three times as long as with those of ordinary bronze.

2d. As regards the liquation, the addition of phosphorus is without any direct effect; but this liquation can be completely avoided by quickly cooling the casting in ingot-molds, a process which gives, at the same time, the maximum of resistance, (strength.)

3d. Taking into consideration only the trials of rapid cooling with ordinary bronze, and the trials with the same cooling for phosphorous bronze, with a mixture of ten per cent. of inferior tin, we have, as the mean of the trials, five for ordinary bronze and six for phosphorous bronze, of each metal under these conditions, and a proportion of 2.50 per cent. of cavities for ordinary bronze, and 1.48 per cent. with phosphorous bronze. In this view, then, the latter metal has the advantage.

4th. In consequence of the smaller yield of tin and the complete disappearance of the dissolved oxides, phosphorous bronze presents a composition

and a fracture much more homogeneous than ordinary bronze, from which there ought to result a greater resistance to abrasion in the bore of a gun. Thus, while ordinary bronze nearly always fails to present a close mixture at the point of fracture, phosphorous bronze acquires a structure perfectly homogeneous, and analogous to that of fine-grained steel.

RÉSUMÉ AND GENERAL CONCLUSIONS.

A metal for cannon, in order to fulfill every desired condition, should possess not only a great *absolute* resistance, but also a high *elastic* resistance; absolute homogeneity of composition; the greatest endurance against the effect of the combustion of gunpowder; a perfect uniformity of results; great hardness; a fusibility sufficient to permit of the easy conversion of condemned pieces into new ones; and, as much as possible, a good relative market value. Now, rejecting the smelting which gives results very inferior to those we have obtained, there remain only steel and bronze.

If it is true that steel possesses, in a very high degree, certain of the qualities which we have enumerated—it does not possess all of them; but its greatest inconvenience lies in its exorbitant price. Thus, a cast-steel cannon of 4, system Wahrendorff, weighs 272 kilogrammes, and costs about 2,100 francs—7.70 francs per kilogramme—and this price increases in a greater ratio than the weight, to such an extent that for pieces of large caliber the price becomes excessive.

Now, a cannon of this kind, rendered unserviceable, becomes absolutely of no value, the steel not even selling at the price of old iron.

The series of trials by which we established these results demonstrated that it was necessary to discard the use of manganese, of nickel, and of iron in the alloys for cannon; that the phosphide of copper could no more be employed, and that the addition of zinc, much as it increases the resistance, does not give satisfactory results in other respects. There remain, then, only the ordinary bronze and the phosphorous bronze; and we have shown, in the conclusions arrived at from our trials with this latter alloy, that it is in every way much superior to ordinary bronze.

As for resistance, it is seen how the sum of the trials of phosphorous bronze is superior to that of the trials of ordinary bronze; but if we take, for comparison, the five trials with ordinary bronze cooled rapidly and the six trials of phosphorous bronze cooled with equal rapidity and containing less than 10 per cent. of tin, we find that the mean of the *elastic* resistances of the last six trials is to the mean of the first five as 135 is to 100, and the mean of the *absolute* resistances of the original section as 180 to 100.

If we compare the best result obtained with ordinary bronze, cast in the usual manner, that is, with slow cooling, and phosphorous bronze which has given the best result, for instance, No. 39, containing 5 per cent. of tin, we find for the first an *elastic* resistance of 907 kilogrammes and an *absolute* resistance of 1,352 kilogrammes; and for the second, an *elastic* resistance of 1,673 kilogrammes and an *absolute* resistance of 3,699 kilogrammes; that is to say, that the *elastic* resistances are in the proportion of 100 to 184, and the *absolute* resistances of 100 to 274.

* * * * *

All things considered, we obtain, by the addition of phosphorus to ordinary bronze, combined with casting in an ingot-mold, a metal having a hardness approaching that of steel; an elastic and absolute resistance varying between 60 and 174 per cent. above ordinary bronze; a composition more homogeneous than that bronze, and consequently resisting better the effects of the combustion of gunpowder. Finally, a metal costing but very little more than ordinary bronze, and, being of better quality, unserviceable guns that were made of it can be used again in the fabrication of new pieces. Moreover, this metal, costing altogether not half the price of steel, possesses all its original value as metal after being worn out in cannon.

Recapitulation of the principal data

Numbers.	NAME OF THE ALLOYS.	COMPOSITION OF THE ALLOY.							Specific gravity of the bar.	Specific gravity of a sample.
		Copper.	Tin.	Nickel.	Manganese.	Iron.	Zinc.	Phosphorus.		
1	Ordinary cannon bronze.....	90	10	.....	.....	.....	.....	.....	8.623	8.836
2	Do	90	10	.....	.....	.....	.....	.....	8.746	8.870
3	Do	90	10	.....	.....	.....	.....	.....	8.664	8.981
4	Do	90	10	.....	.....	.....	.....	.....	8.710	8.882
5	Do	90	10	.....	.....	.....	.....	.....	8.728	8.872
6	Do	90	10	.....	.....	.....	.....	.....	8.704	8.906
7	Do	90	10	.....	.....	.....	.....	.....	8.741	8.877
8	Do	90	10	.....	.....	.....	.....	.....	8.517	8.839
10	Manganese-copper	95	.....	.....	5	.....	.....	.....	8.668	8.766
11	Do	90	.....	.....	10	.....	.....	.....	8.492	8.630
12	Manganese-bronze	90	5	.....	5	.....	.....	.....	8.570	8.817
13	Do	85	10	.....	5	.....	.....	.....	8.618	8.804
14	Do	80	10	.....	10	.....	.....	.....	8.453	8.606
15	Cupreous nickel	95	.....	5	.....	.....	.....	.....	8.662	8.942
16	Do	90	.....	10	.....	.....	.....	.....	8.625	8.973
17*	Bronze with nickel	90	5	5	.....	.....	.....	.....	8.760	8.947
18	Do	85	5	10	.....	.....	.....	.....	8.620	8.963
19	Do	75	5	20	.....	.....	.....	.....	8.747	8.926
20	Do	85	10	5	.....	.....	.....	.....	8.727	8.966
21	Do	80	10	10	.....	.....	.....	.....	8.741	9.005
22	Ferruginous bronze	85	10	.....	.....	5	.....	.....	8.610	8.809
23	Zinciferous bronze	88	10	.....	.....	.....	2	.....	8.752	8.880
24	Pure copper	100	.....	.....	.....	.....	.....	.....	8.416	8.760
25	Phosphorous copper	99.3	.....	.....	.....	.....	.....	0.7	8.729	8.870
26	Do	98.7	.....	.....	.....	.....	.....	1.3	8.590	8.739
27	Phosphorous bronze	90	10	.....	.....	.....	.....	trace.	8.707	8.816
28	Do	89.75	10	.....	.....	.....	.....	0.25	8.539	8.842
29	Do	89.40	10	.....	.....	.....	.....	0.60	8.152	8.626
30	Do	89.25	10	.....	.....	.....	.....	0.75	8.678	8.832
31	Do	89.25	10	.....	.....	.....	.....	0.75	8.318	8.709
32	Do	90.10	9	.....	.....	.....	.....	0.90	8.557	8.716
33	Do	93.50	5	.....	.....	.....	.....	1.50	8.524	8.675
34	Do	89.90	8.5	.....	.....	.....	.....	1.60	8.476	8.583
35	Do	89.90	8.5	.....	.....	.....	.....	1.60	8.487	8.590
36	Do	89.90	8.5	.....	.....	.....	.....	1.60	8.305	8.605
37	Do	92.	6.2	.....	.....	.....	.....	1.80	8.517	8.612
38	Do	87.10	10.6	.....	.....	.....	.....	2.30	7.792	8.469
39	Do	92.50	5	.....	.....	.....	.....	2.50	8.394	8.546
40	Do	92.50	5	.....	.....	.....	.....	2.50	8.070	8.507

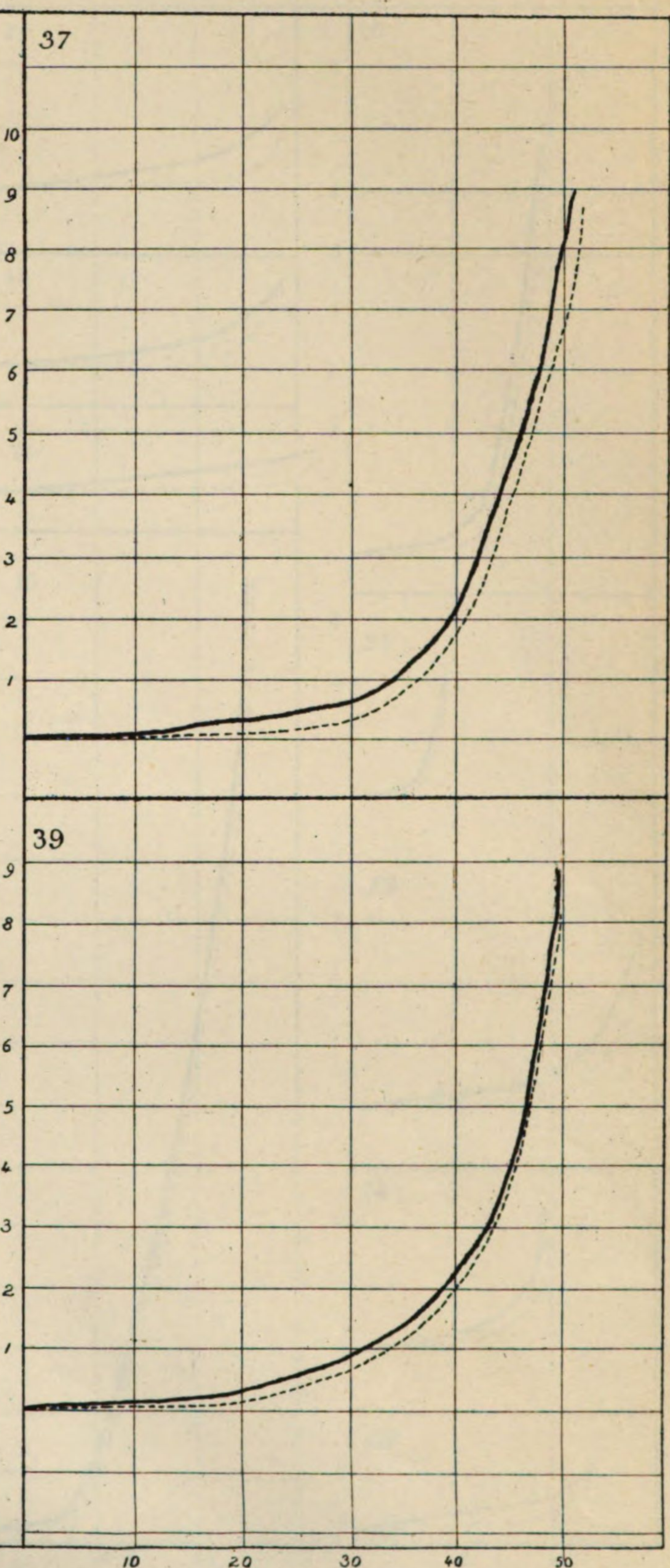
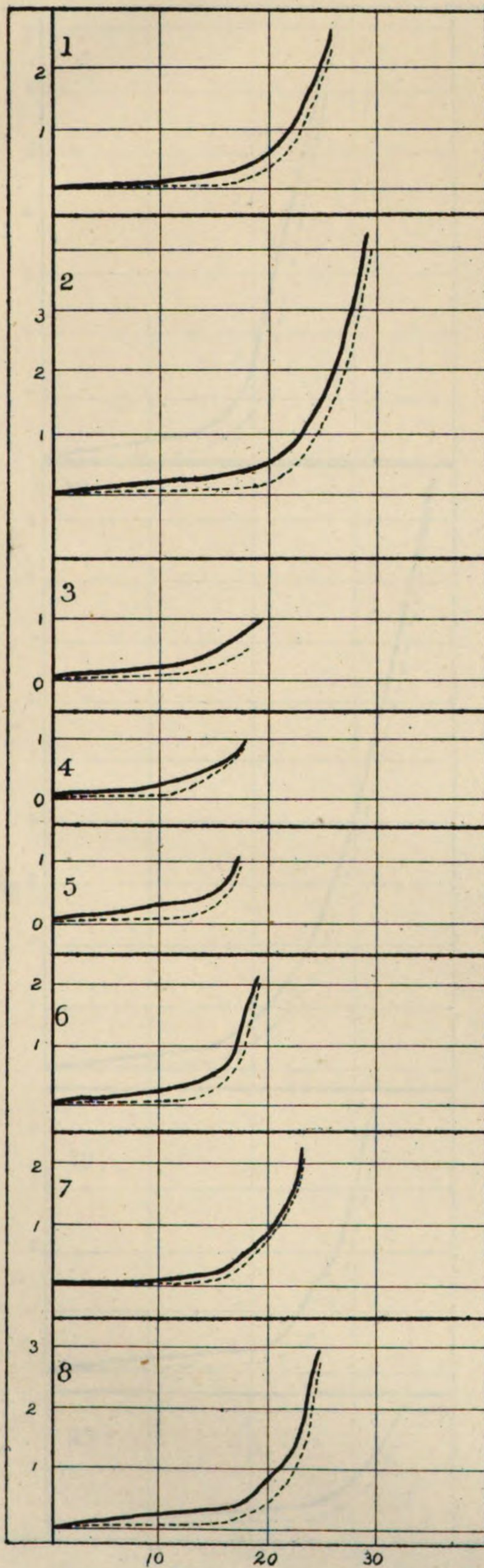
of the trials of resistance.

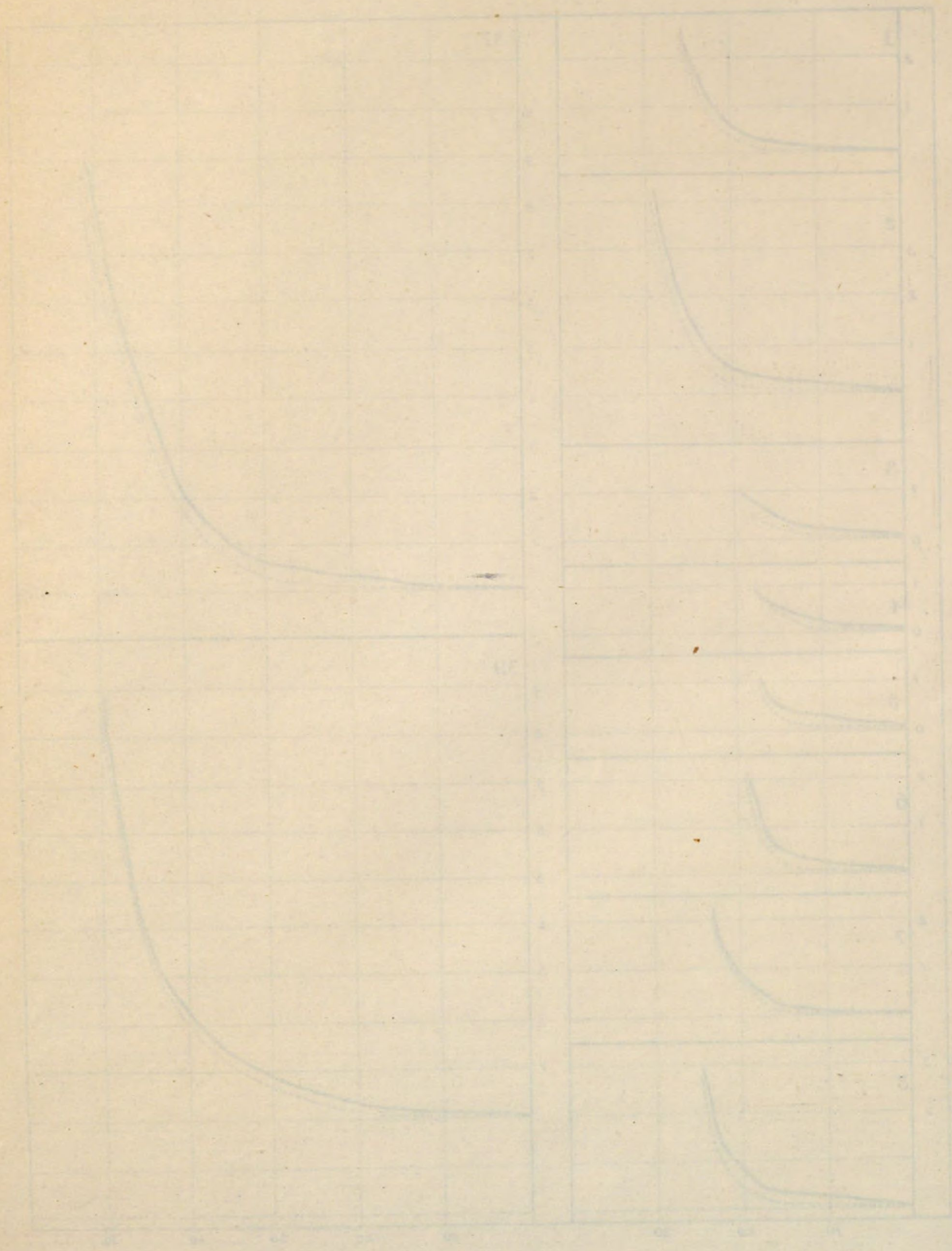
Cavities in the bar.	Temperature of the casting.	Mode of cooling.	Diminution of the section of rupture.	Final permanent elongation.	Elastic resistance.	Absolute resistance calculated on the original section.	Absolute resistance calculated on the section of rupture.	Numbers.	Pages.	Remarks.
<i>Per ct.</i>			<i>Per ct.</i>	<i>Per ct.</i>	<i>Kilog.</i>	<i>Kilog.</i>	<i>Kilog.</i>			
2.41	2309° C.	Quickly.	5.10	2.7	1075	1769	1863	1	18	The resistances are expressed in kilogrammes per square centimetre.
1.41	1602° C.	...do	8.4	4.0	1385	2076	2266	2	20	
3.33	1338° C.	...do	5.0	2.4	1012	1365	1437	3	22	
1.94	2420° C.	Slowly ..	3.6	1.0	900	1170	1214	4	24	
1.62	1595° C.	...do	3.7	1.4	935	1163	1200	5	26	
2.27	1363° C.	...do	3.3	2.0	907	1352	1398	6	28	
1.53	1595° C.	Quickly.	3.2	2.0	1209	1616	1670	7	32	
3.63	1668° C.	...do	3.2	2.8	1244	1755	1813	8	34	
1.13	1615° C.	Slowly ..	16.7	6.8	731	1372	1647	10	40	
1.60	1622° C.	...do	18.3	8.3	1082	1868	2287	11	42	
2.81	1433° C.	Quickly.	8.4	1.8	1033	1360	1496	12	44	No. 9, containing phosphorus, corresponds to No. 27.
2.11	1517° C.	...do	6.7	1.7	1402	1995	2140	13	46	
1.78	1672° C.	...do	1.5	0.6	1975	2240	2275	14	48	
3.13	1692° C.	Slowly ..	27.6	14.7	.....	1682	2325	15	52	
3.88	1760° C.	...do	26.1	15.6	520	1830	2472	16	54	
2.11	1700° C.	Quickly.	21.5	7.2	1118	1972	2518	17	57	
3.83	1737° C.	...do	15.1	9.7	1334	2665	3140	18	59	
2.01	1749° C.	...do	10.1	3.8	1440	2220	2470	19	61	
2.66	1656° C.	...do	3.3	1.0	1263	1621	1677	20	63	
2.94	1626° C.	...do	1.5	1.1	1568	2032	2055	21	65	
2.28	1680° C.	...do	6.7	2.9	1321	2012	2156	22	68	The elastic resistance is less than 700 kilogrammes.
1.44	1648° C.	...do	6.7	1.8	1708	2459	2636	23	71	
3.93	1360° C.	Slowly ..	3.30	1.8	309	490	507	24	75	
1.59	1602° C.	...do	33.5	23.8	466	2245	3365	25	76	
1.71	1572° C.	...do	23.0	24.7	682	2805	3642	26	78	
1.24	1514° C.	Quickly.	6.7	6.8	1356	2384	2558	27	86	
3.43	1650° C.	...do	3.3	1.9	1237	1866	1930	28	88	
5.50	1613° C.	...do	2.8	1.5	1596	2567	2622	29	90	
1.80	1435° C.	...do	1.5	1.5	1736	2834	2879	30	92	
4.50	1397° C.	Slowly ..	1.5	1.8	1413	1977	2007	31	94	
1.81	1457° C.	Quickly.	3.3	2.0	1392	2246	2323	32	97	This trial corresponds to No. 9. It is placed here on account of the addition of phosphorus.
1.74	1472° C.	...do	6.7	6.2	1462	2636	2826	33	99	
1.25	1481° C.	...do	1.5	1.6	1708	2900	2943	34	101	
1.20	1698° C.	...do	1.5	1.6	1736	3241	3290	35	103	
3.36	1380° C.	Slowly ..	1.5	1.5	1448	2028	2059	36	105	
1.11	1400° C.	Quickly.	10.1	10.7	1518	3630	4039	37	108	
8.00	1511° C.	...do	0.2	1.0	1539	1788	1791	38	110	
1.77	1451° C.	...do	8.4	7.8	1673	3699	4039	39	112	
5.13	1373° C.	Slowly ..	2.2	2.4	1455	2246	2236	40	114	

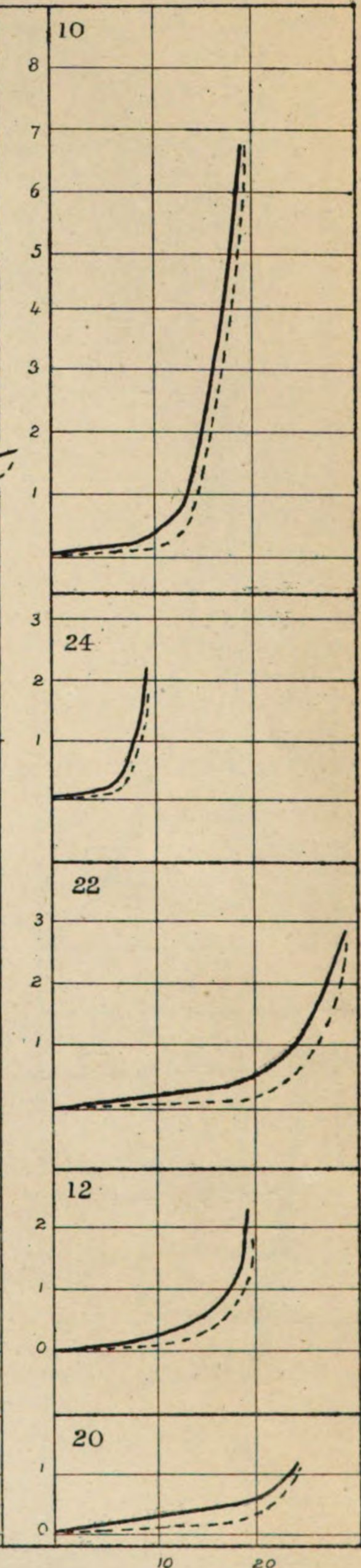
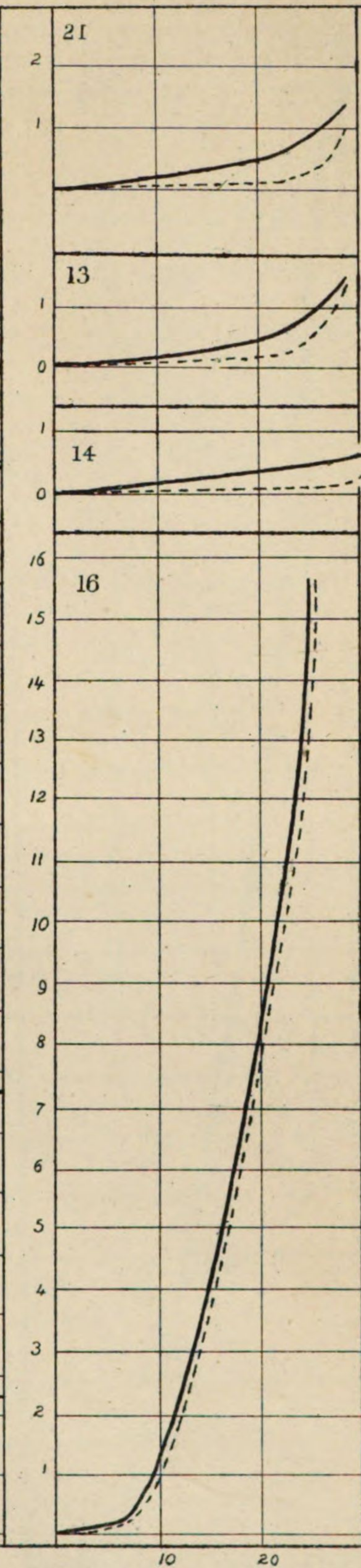
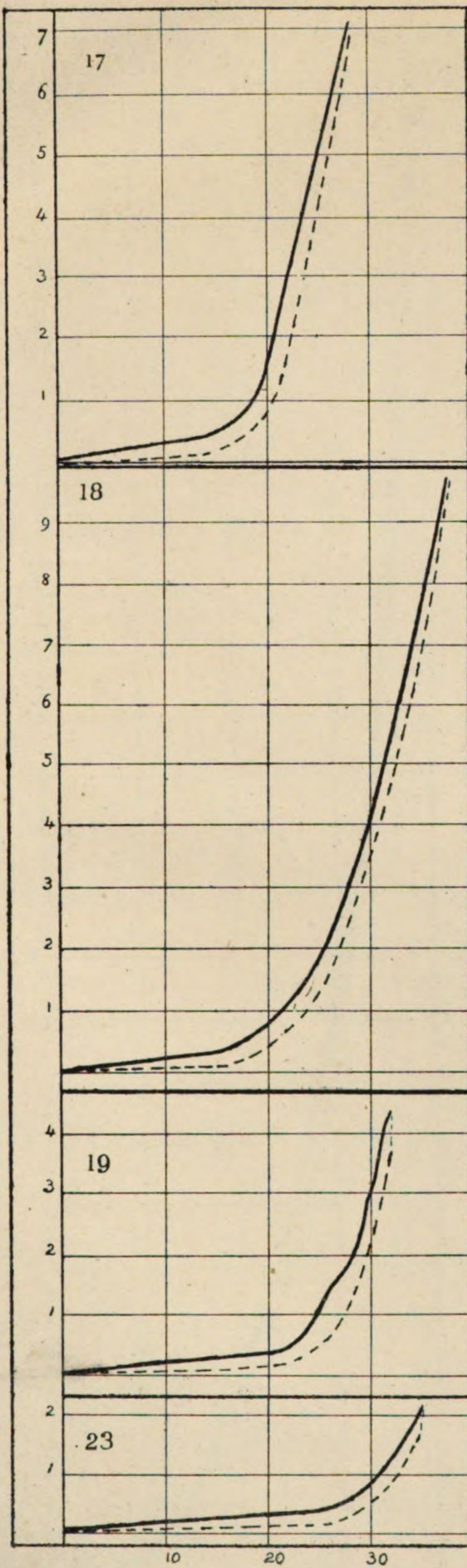
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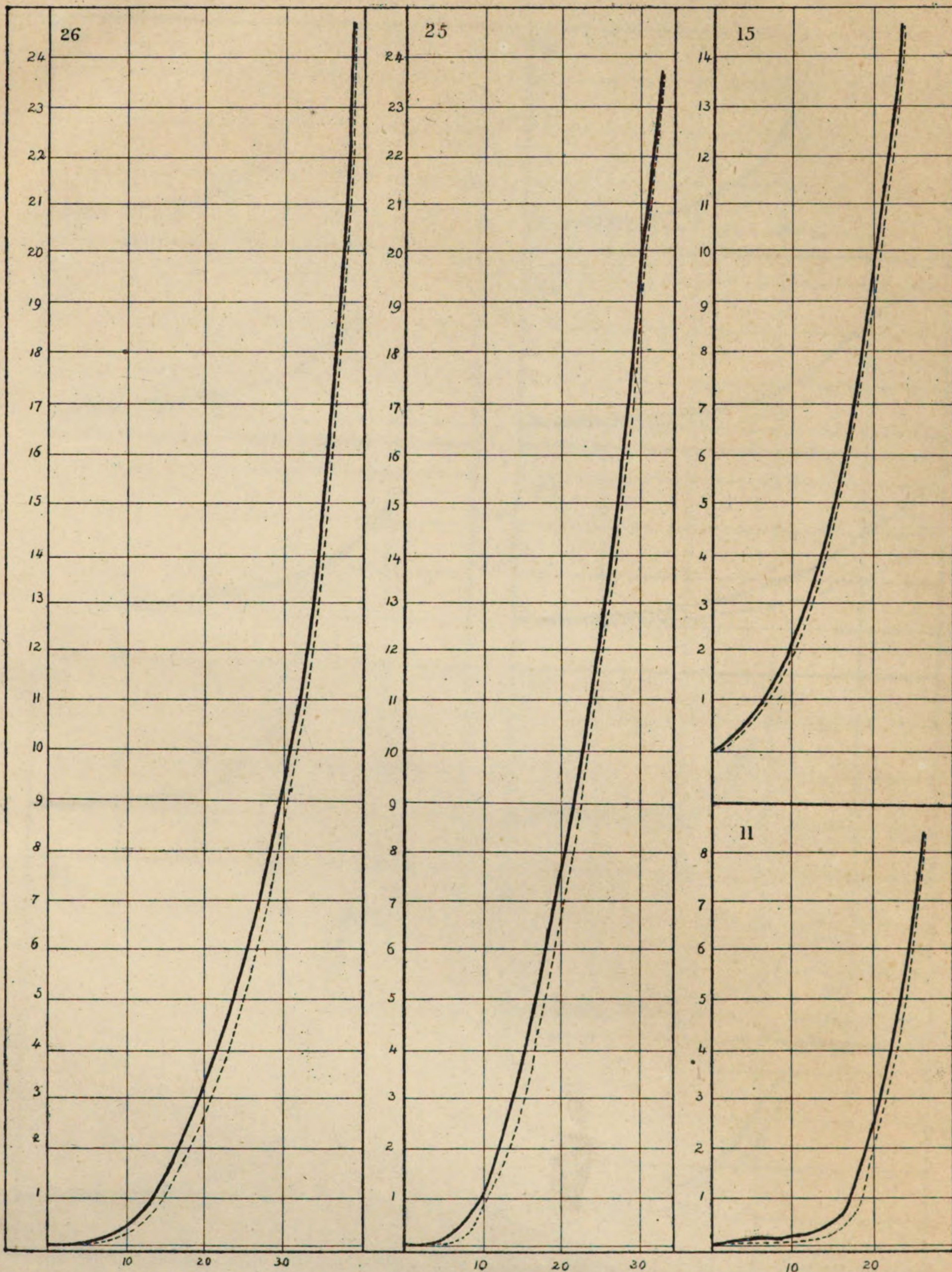
1.	Ordinary cannon-bronze, cooled quickly.		
2.	Do.	do.	do.
3.	Do.	do.	do.
4.	Do.	do.	slowly.
5.	Do.	do.	do.
6.	Do.	do.	do.
7.	Do.	do.	quickly.
8.	Do.	do.	do.
10.	Manganese-copper,	do.	slowly.
11.	Do.	do.	do.
12.	Manganese-bronze,	do.	quickly.
13.	Do.	do.	do.
14.	Do.	do.	do.
15.	Cupreous nickel,	do.	slowly.
16.	Do.	do.	do.
17.	Bronze with nickel,	do.	quickly.
18.	Do.	do.	do.
19.	Do.	do.	do.
20.	Do.	do.	do.
21.	Do.	do.	do.
22.	Ferruginous bronze,	do.	do.
23.	Zinciferous bronze,	do.	do.
24.	Pure copper,	do.	slowly.
25.	Phosphorous-copper,	do.	do.
26.	Do.	do.	do.
27.	Phosphorous-bronze,	do.	quickly.
28.	Do.	do.	do.
29.	Do.	do.	do.
30.	Do.	do.	do.
31.	Do.	do.	slowly.
32.	Do.	do.	quickly.
33.	Do.	do.	do.
34.	Do.	do.	do.
35.	Do.	do.	do.
36.	Do.	do.	slowly.
37.	Do.	do.	quickly.
38.	Do.	do.	do.
39.	Do.	do.	do.
40.	Do.	do.	slowly.

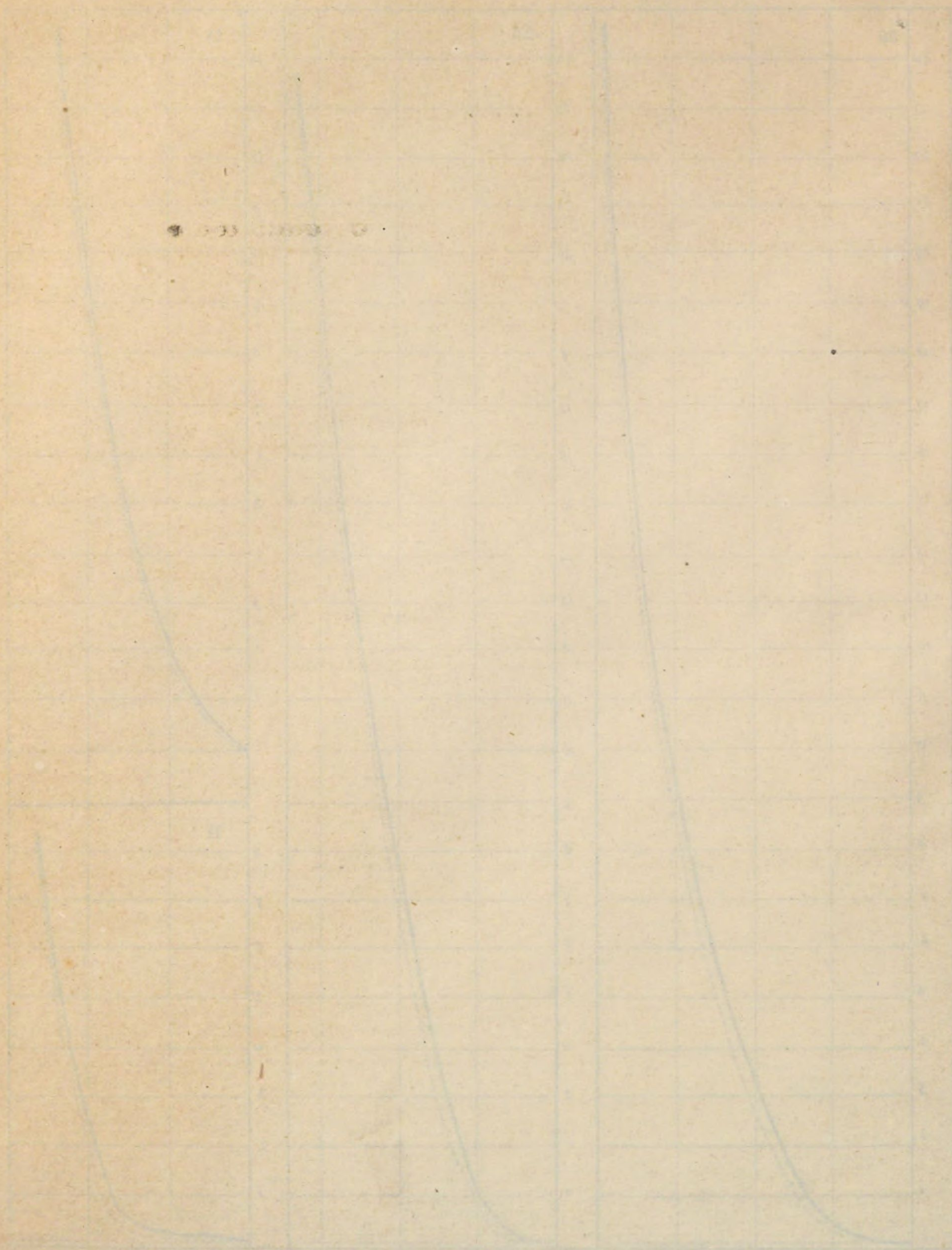
N. B.—The horizontal lines represent the elongations of the original length in hundredths, and the vertical lines the tensile strains in thousands of English pounds. The numbers of the curves correspond to those of the text.

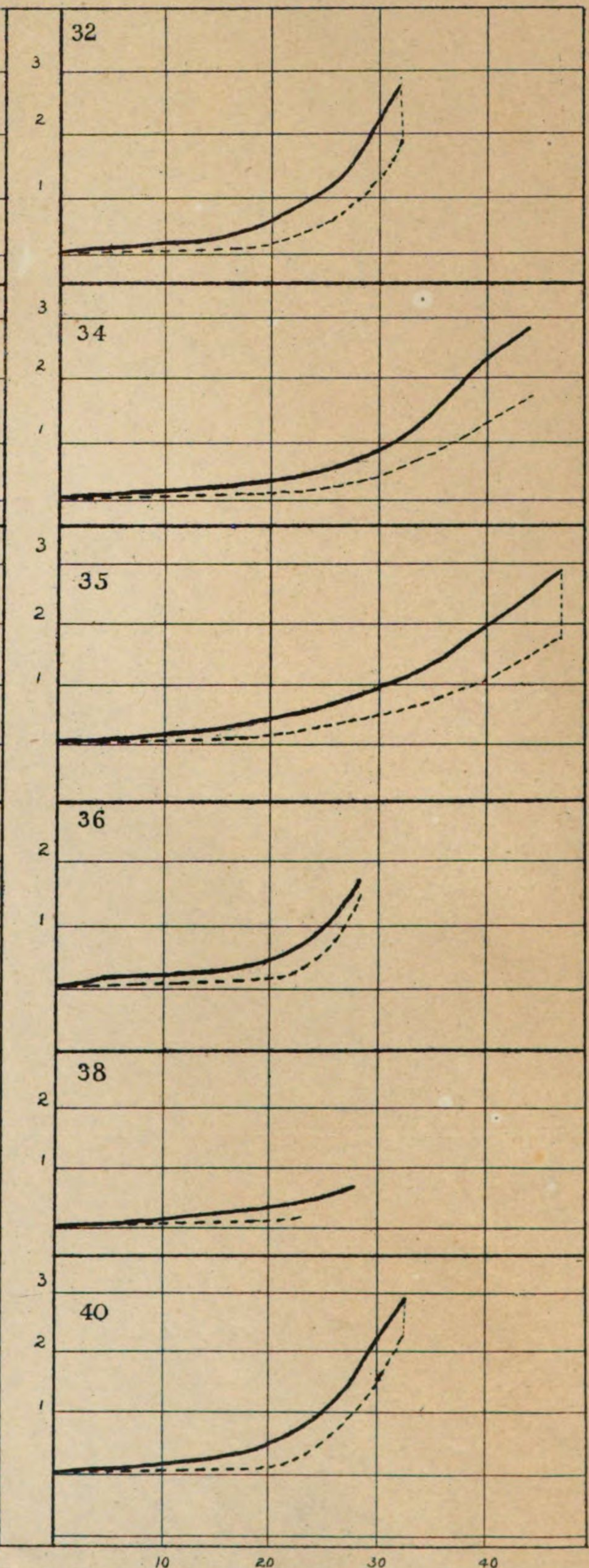
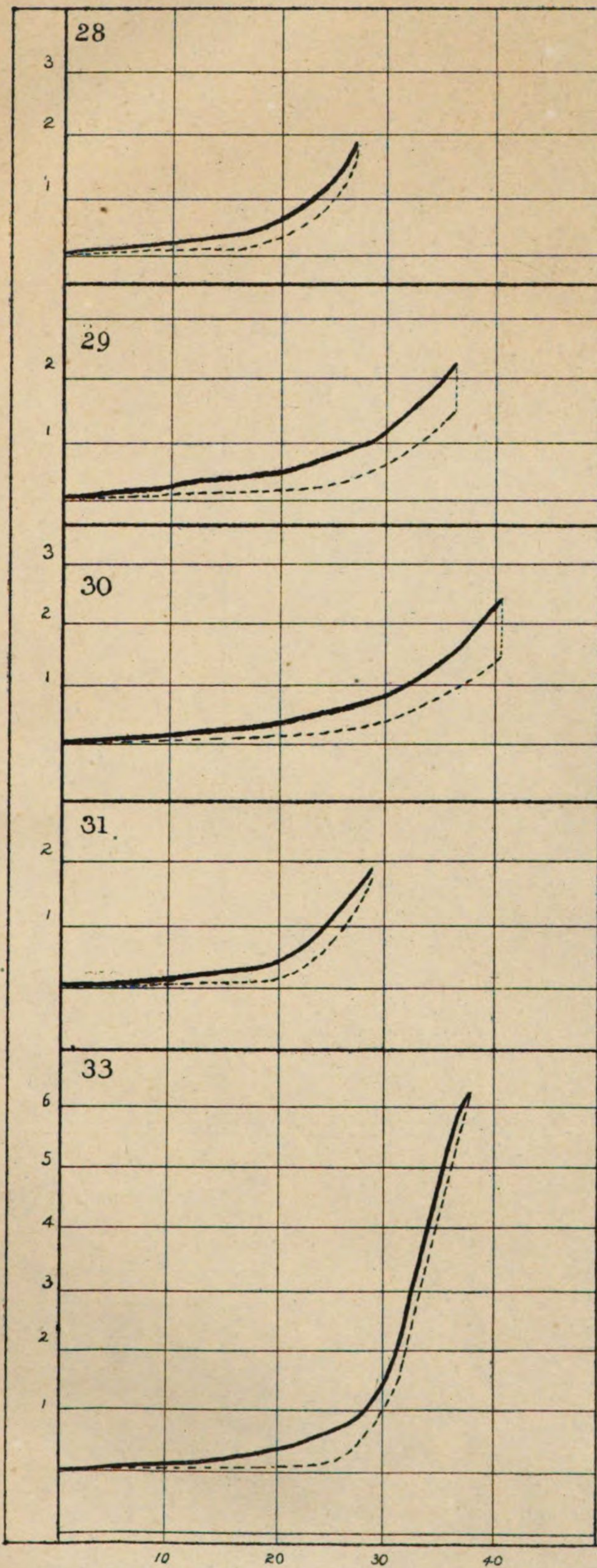


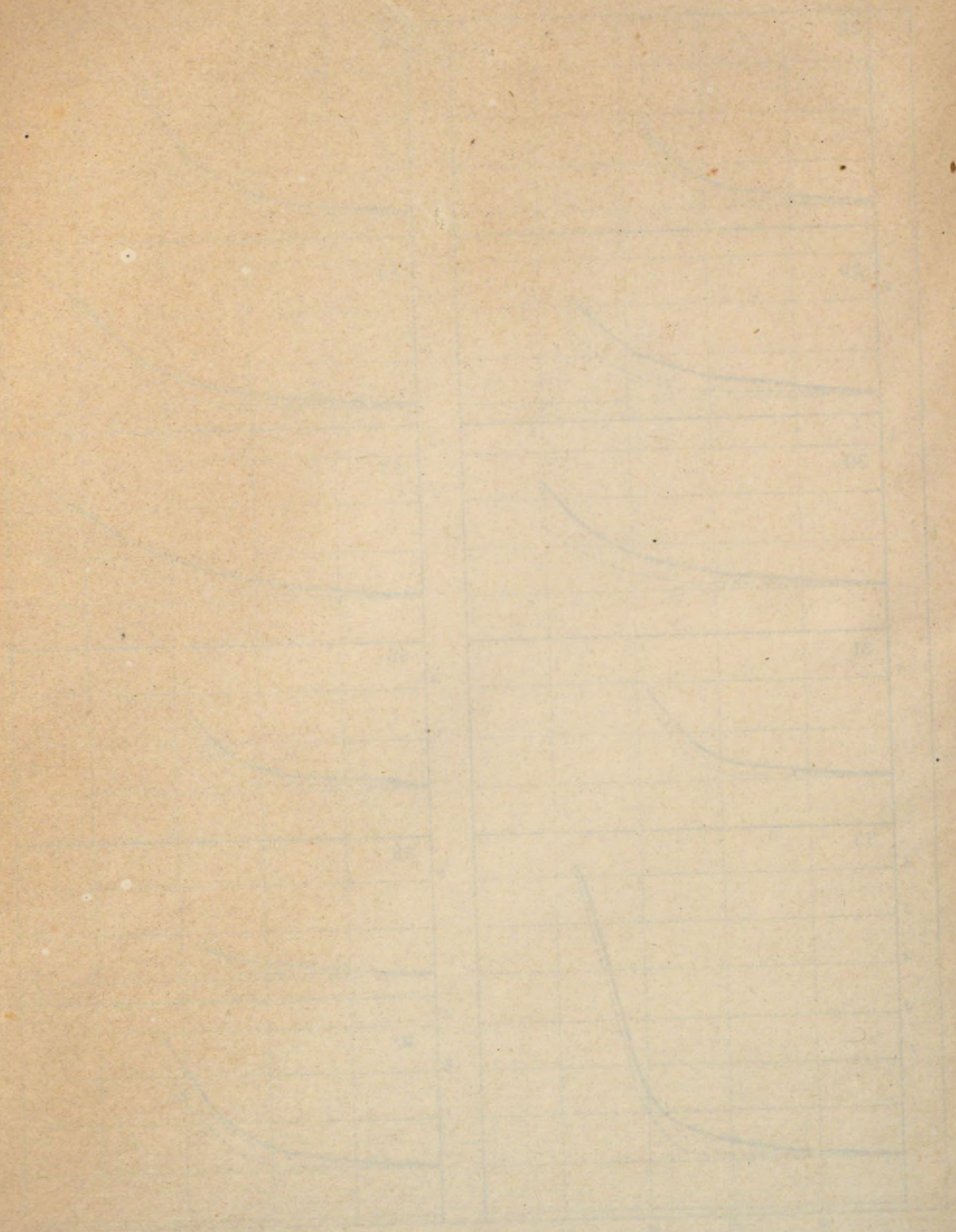












Montefiore, G.

Essay on the use of various Alloys, especially of Phosphorus Bronze, for the Founding of Cannon By G. Montefiore and C. Kunzel. Brussels, 1870. Translated from the French by John D. Brandt, chief clerck, B. O., Navy Dep

Washington 1872

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